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TRANSMISSION TIME.*

OTTO KLOTZ.

FOR POPULAR ASTRONOMY.

In connection with the international determination of the one hundred and forty-first meridian, being part of the boundary line between Canada and Alaska, during the past season, it was desirable to determine whether, by use of automatic repeaters, the transmission time in the one direction was the same as in the other. Between the Observatory at Vancouver and the observing hut on the Yukon there were repeaters, at the four stations, Vancouver, Ashcroft, Hazelton and Atlin.

The repeaters, of the Weiny-Phillips type, were all alike, and their adjustments very similar, yet there was no absolute assurance that the transmission time was exactly the same in the two directions. It was not found practicable during the nights of the longitude campaign to make the necessary changes for alternately sending in a different direction through the repeaters, so the day immediately following the completion of the longitude work was devoted thereto and the necessary experiments made. The Observatory at Vancouver is about three miles from the C. P. R. telegraph office, and has the single wire connecting it, grounded.

The distances are:

Vancouver to Ashcroft	204 miles
Ashcroft to Hazelton	587 "
Hazelton to Atlin	515 "
Atlin to Boundary	668 "
Vancouver to Boundary	1974 "

In round numbers the distance is 2000 miles.

The iron wire is of No. 8 Birmingham guage, weighing 360 pounds to the mile.

The distribution of E. M. F. was as follows:

Ashcroft	60	gravity cells	west, 132	north;
Hazelton	115	" "	south, 85	;
Atlin	65	gravity cells	south, 154	north;
Dawson	150	" "	straight	
Egbert	96	" "	"	

* Communicated by permission of Chief Astronomer.

Egbert is about ten miles beyond or west of the one hundred and forty-first meridian in Alaska.

At Vancouver 100 volts, storage cells were used.

The time-pieces were two Dent sidereal chronometers, each having two-second electric breaks, and the recording was done on Fauth cylinder chronographs, the records being read by a tenth-second glass scale, and by estimation to the hundredth of a second. The experiment consisted in sending arbitrary signals by means of a break-circuit key alternately by the two observers, i.e., the one would send twenty signals, the other forty, and then again the first twenty, so that the middle time for each observer would be about the same. The conditions under which the signals were sent on that day (September 3) were as follows: (1) the usual arrangement as in commercial work and that of the longitude work; (2) repeaters reversed; (3) repeaters and poles reversed; and (4) same as (1).

It may be remarked that there was no change made in the adjustment of the points in the repeaters in the various conditions, and all the other offices on the line were cut out, as in the longitude work.

The following is the record;

Condition	Direction	Vancouver Middle Time. h	m	s	Diff. of Chronometer	Differential Rate Corr. s	Diff. of Chron. for same epoch.	Total transmission time, going & coming. s
(1)	Western sigs.	13	57	56	1—09—59.129	.000	1—09—59.129	
(1)	Eastern "	14	04	56	58.667	+.011	58.678	.451
(2)	" "	14	12	03	58.647	.022	58.669	
(2)	Western "		14	36	59.079	.026	59.105	.436
(3)	" "	15	16	15	58.963	.123	59.086	
(3)	Eastern "		19	49	58.542	.128	58.670	.416
(4)	" "	15	33	27	58.542	.153	58.695	
(4)	Western "		35	25	58.962	.156	59.118	.423

Taking the mean of (1) and (4) $= {}^{s}.437$ and the mean of (2) and (3) $= {}^{s}.426$

We have $t + t' = {}^{s}.4315$
$t - t = .0225$

Whence $t = .2270$
$t' = .2045$

Where t = transmission time with repeaters, going west
t' = " " " " East.

Apparently the transmission time going east, i.e., from Boundary to Vancouver is $^{s}.022$ less than going in the opposite direction. We say apparently, for the inter-agreement of (1) with (4), and (2) with (3), which should be identical, is of a mag-

nitude of that quantity. It is therefore not certain whether the difference of transmission times found for the two directions is apparent or real. In any case it is a very small quantity; the correction being a hundredth of a second of time, or less than seven feet at the Yukon boundary.

The mean transmission time is at the rate of 9,400 miles per second.

THE SIGNIFICANCE OF THE STAR-RATIO.*

GEORGE C. COMSTOCK.

The number of visible stars increases very rapidly as we extend the count to fainter and fainter magnitudes, and any rational attempt at their enumeration must involve a limit, or limits, of brightness at which that enumeration shall cease. The rate of increase in the number of stars as this limit is made to move down the scale of magnitudes is called the star ratio, and the numerical value of this ratio in different parts of the sky and at different points in the scale of stellar magnitudes has been made the subject of research by many astronomers. From these investigations it appears that in general the number of stars is increased more than threefold and considerably less than fourfold for each increase of one magnitude in the limit to which the enumeration is extended. The ratio appears to be a little greater in the milky way than in extra-galactic regions and possibly a little greater for the brighter magnitudes than for the fainter ones, although it seems probable that the last relation is confined to the region outside the galaxy.

The point of major interest in the discussion is, however, that in general the rate of increase is decidedly less than fourfold, while a very simple analysis shows that if the stars are strewn with some rough uniformity of distribution throughout a region of indefinitely great extent, the average star ratio should be very approximately a fourfold increase per magnitude. The disparity between this theoretical ratio and that found actually to obtain, throws discredit upon the hypothesis above made with respect to the distribution of the stars, and there has been reared upon it the current concept which represents the stellar system as of finite and measurable extent, broader in the galaxy be-

* Abstract of paper read before the New York meeting of the Astronomical and Astrophysical Society of America.

cause here the star ratio is relatively large, smaller at right angles to the milky way because here the star ratio diminishes. The idea is that the faint stars are faint because of their greater distance and are more numerous because the volume of space in which they may be distributed increases with the cube of the distance. But if the stellar system reaches out only to a certain limit and the space beyond is void, it can contribute nothing to the number of stars; and the star ratio, while everywhere below the value that would obtain for an infinite system, ought to diminish very rapidly as we approach the confines and deal with stars fainter than any that have been hitherto enumerated, although Professor Pickering holds that even within the range of magnitudes covered by his investigations, such a diminution in the value of the ratio is distinctly shown.

The present paper controverts the views above outlined and shows that the supposed fourfold ratio that constitutes their theoretical basis has been erroneously derived through ignoring an essential factor of the problem. The faint stars appear faint not only because of their greater distance, but because they actually emit less light than do the brighter ones, and because of this inferior luminosity they are nearer than has been assumed. This diminished distance is shown by observation of their proper motions and because of it we have a diminished space available for the faint stars; they are less numerous and the star ratio smaller than is required by the erroneous theory above considered. When the diminishing intrinsic brightness of the fainter stars is properly taken into account the author finds from a discussion of the star ratio for galactic stars down to the faintest yet enumerated (the Herschel gauges), that there is here no indication of an accessible limit to the stellar system.

Outside the galaxy the conditions are different, the values of the star ratio are progressively smaller and suggest some one of the following alternative conditions or possibly a combination of them:

(a) At right angles to the galaxy the limits of the stellar system fall within the range of vision, as indicated above.

(b) The stars remote from the plane of the galaxy are on the average progressively less luminous than those in the galaxy.

(c) The transmission of light through the extra-galactic spaces is impeded by some absorbing medium which serves to diminish the brilliancy of the stars in larger measure than is the case in the galaxy.

Any of these alternatives will serve in explanation of the observed facts and it is not now feasible to make definite choice among them.

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THE METHOD OF USING PROFESSOR NEWCOMB'S TABLES OF THE PLANETS.

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FOR POPULAR ASTRONOMY.

1. *Retrospect.* From the earliest times, tables of the planets have been prepared; but treating of epicycles, they were not of much value until Copernicus made known his system of the heavens, and about 1627 when Kepler announced his three great laws of planetary motion, one of which was that the planets move in ellipses, planetary astronomy began to assume a rigorous aspect and the *Equation of the Center* then became known. Sir Isaac Newton about the beginning of the eighteenth century made a great step forward when he announced the law of universal gravitation,—the mutual attraction of each planet towards all the others; and a new problem was added to the preparation of the tables,—the calculation of the perturbations.

But it was left to the Marquis de Laplace to put into practical shape for actual use the laws of Newton; and by his formulæ, published in the *Mechanique Celeste* in 1782 the perturbations are usually computed. They are applied as corrections to the true anomaly, an important point, to be referred to again. Laplace also discovered the *Great Inequality* subsisting between Jupiter and Saturn. Their motions are such that Jupiter makes one revolution in about twelve years, and Saturn in thirty years, nearly, consequently if they start while in conjunction in longitude, in twenty years Jupiter will have 1⅔ revolutions and Saturn ⅔. They will therefore be in conjunction in longitude 240° from where their first position. After twenty years again Jupiter will have made 3⅓ revolutions and Saturn 1⅓ and they will again be together distant in their orbits 120° from the point they started, and in twenty years more they will again be together in the longitude of the starting point. The *Nautical Almanac* gives the conjunction of these planets in right ascension 1901 November 27, but they were in conjunction in longitude September 28, their longitude then being 285°. Their

next conjunction in 1921 will be in longitude 165° and the next succeeding 1941, in longitude 45°, and in 1961 together again at 285°. These giant planets being together only at these three points of the heavens, exert a great influence not only upon each other, but upon all the other planets.

About this time, the world was startled by the discovery of Uranus in 1781 by Sir William Herschel. No major planet had been added to the solar system since the earliest times. Its orbit was computed by the method then in use of assuming a circular orbit and calculating the eccentricity and other elements two or more approximations were then necessary. This planet was so readily seen that the question arose whether it may not have been previously seen; so an ephemeris was constructed running back a number of years, and compared with the observations of stars made at various observatories, resulting in the discovery of sixteen positions regarded as fixed stars where no stars now appear. These ancient observations as they are styled were of great use in determining the elements of the orbit.

This indirect method of computing an orbit was applied in all cases, notwithstanding the result may be a parabola or hyperbola of great eccentricity; and its application to so important an orbit as that of a major planet, undoubtedly led the German astronomer Charles Frederic Gauss to examine the problem. His result was another step forward in the science of astronomy, published in his *Theoria Motus Corporum Coelestum* giving the method of computing an orbit *de novo* from three complete observations. But as there usually are many more than three observations, Gauss also made known his Method of Least Squares whereby any number of observations may be combined into the most probable values of three, from which the elements of the orbit are then determined, This method was first applied to the asteroid Ceres discovered January 1, 1801; but the above mentioned work was not published until 1809. An English translation was made in 1857 by Commander, afterward Rear Admiral Charles Henry Davis, U. S. N., the first Superintendent of the *American Ephemeris and Nautical Almanac*.

Gauss' *Theoria Motus* is rather a difficult work to read, even the English translation. A more easy work upon the same subject is Professor James C. Watson's *Theoretical Astronomy* published in 1885.

Tables of the Planets. Various tables have been published from time to time and by various authors, but only those may be mentioned here which have been used upon the *American*

Ephemeris and mentioned in the Appendix to each volume. Carlini's Tables of the Sun, and subsequently Hansen and Olufsen's, Lindenau published in Latin, Tables of Mars in 1811 and also Tables of Venus. Bouvard in 1821, Tables of Jupiter, Saturn and Uranus (Neptune not then having been discovered) Professor Winlock, superintendent of the *Nautical Almanac*, Tables of Mercury 1864; Dr. George W. Hill, Venus, 1873; Professor Simon Newcomb Neptune in 1865 and Uranus in 1873. Professor Peirce and Mr. Walker published Tables of Neptune, and Professor Peirce Tables of the Moon. Lindenau's Tables of Mars are given to the tenth of a second only, and the quantities taken from them do not difference well showing errors of 0″.2 and 0″.3. They seem to be carelessly printed. On one page the differences have slipped up a little, and to fill the space below another difference is inserted, making one too many for the column. Bouvard's Tables conform to the French centecimal measure, 100° to the quadrant. They difference well.

Bouvard's Tables of Uranus 1821 deserve especial notice. He found a discrepancy between the ancient observations and the modern, when comparing them with his tables, and thus writes:

"Such then is the alternative presented in the formation of the tables of the Planet Uranus, that if we combine the ancient observations with the modern, the former will be passably represented, while the latter will not be represented with the precision which they possess; and if we reject some only to preserve others, the Tables will result which will have all the exactitude desirable relative to the modern observations; but which will not satisfy conveniently the ancient observations. It will be necessary to decide between these two alternatives. I have held to the second as being that which reunites the greatest probability in favor of the truth; and I leave to times to come, the need of making known if the difficulty of reconciling the two systems is caused really by the inexactitude of the ancient observations or if it depends upon some action, strange and unperceived which took effect on the planet."

How prophetic are these words! Bouvard does not use the word *unknown*, but *strange* and *unperceived*,—"quelque action étrangère et inaperçue". In fact the subsequent history of this difficulty was *strange* in the extreme; these very words of Bouvard led the genius of Leverrier and Adams by a strange and unusual method to the discovery of the planet Neptune, and while it was yet *unperceived* by any human eye. The perturbations of this planet now completely reconcile the ancient and modern observations of Uranus.

Leverrier was the first to publish a full set of Tables of the planets which appeared from time to time between 1874 and 1876, and though they were the best then published yet there is lack of uniformity in the data employed; for example the new and more accurate determination of some constant already used in the earlier tables, would cause the new value to be used in the later ones.

The tables of Professor Newcomb and Dr. Hill are by far the best ever published. They are thoroughly consistent throughout, the perturbations were all carried in at the same time, and the same values of the constants and fundamental quantities were used for all the planets. These tables are in use for all the Nautical Almanacs and are the standard throughout the world.

In this connection there recurs to mind a curious line from the *Essay on Man* by Alexander Pope:—

> Let Earth unbalanc'd from her orbit fly,
> Planets and suns run lawless through the sky.
> Ep. i, l. 251.

This is very bad astronomy although it may be good poetry. The thread which holds together the planets of the solar system is of stronger tenure than the poet suspects. If one of the planets could by any possibility be removed, the others would continue to move on, and with greater regularity than before.

2. General Formulæ, *Notation.* There is but *one* sequence of formulæ by which the longitude, latitude and radius vector of a planet can be computed from the elements; and moreover, the tables of the planets must also necessarily follow this sequence. We will recapitulate these formulæ which may be found in Gauss' *Theoria Motus*, Watson's *Theoretical Astronomy* and other advanced works.

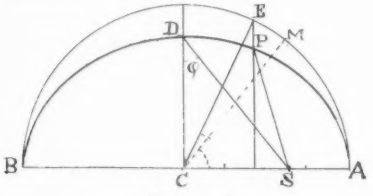


Figure 1

In Figure 1,—a well-known figure in the better class of astronomies, let P be the planet moving in the ellipse of which AB is the transverse axis with the Sun in the focus S, making A the perihelion. The variable line SP is the radius vector and the

angle *PSA* The *True Anomaly* v. On the transverse axis of the ellipse AB describe a circle, and while the planet moves in the ellipse suppose a fictitious planet M to move in the circle with a constant velocity such that if they both start at A they will both arrive at B at the same instant, the true planet moving fast at A with a decreasing velocity towards B. The angle which the line MC makes with the major axis AB is called the *Mean Anomaly* M as it is the mean or average of the motions of the true anomaly v.

From the point P draw a line perpendicular to the transverse axis AB and meeting the circle in the point E, this point is thus geometrically determined, and the angle at the center of the circle ECA is the *Eccentric Anomaly* E. The angle M cannot be *geometrically* located, we can only place our pencil upon the circle somewhere between the perihelion and the point E.

If e is the eccentricity of the ellipse, a very useful transformation is made by placing $e = \sin \phi$ which angle is SDC, for $SD = AC = a$ the semi transverse axis

and $$\sin SDC = \sin \phi = \frac{SC}{SD} = \frac{ae}{a} = e$$

The elements of an elliptical orbit are as follows:

l_0 The mean longitude at a fixed date called the Epoch.
n Mean sidereal motion in one julian year.
π Longitude of the Perihelion.
e Eccentricity of the orbit.
θ Longitude of the Ascending node on the ecliptic.
i Inclination of the orbit to the ecliptic.
a The semi-transverse axis of the ellipse.

We also have as follows:

γ Longitude in orbit.
u Argument of the Latitude or the distance of the planet from node.
ω The distance of the perihelion from the Node.
E The equation of the center.

Between the several quantities above given exist a number of relations which may be found in Gauss and Watson's works, of which we may mention:

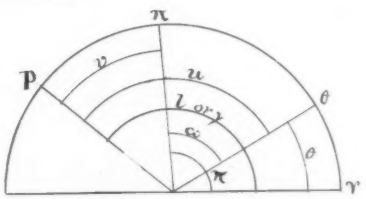


FIGURE 2

$$\gamma = v + \pi = u + \theta$$
$$u = \gamma - \theta = v + \pi - \theta$$

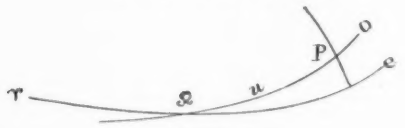


FIGURE 3

The quantity γ here represents a *broken line* measured along the ecliptic from the first point of Aries ♈ to the node Ω and from there along the orbit to the planet P. The reduction to the ecliptic Fig. 3 is a small quantity, the difference between the hypothenuse and base of this spherical triangle which being subtracted gives the base.

$$Re = u - l + \theta = \tan^2 \tfrac{1}{2} i \sin 2u - \tfrac{1}{2} \tan^4 \tfrac{1}{2} i \sin 4u + \tfrac{1}{3} \tan^6 \tfrac{1}{2} i \sin 6u - \text{etc.} \quad (1)$$

Then

$$l = \gamma - Re$$

When Re is tabulated the negative sign is regarded so that in using the tables we have the formula

$$l = \gamma + Re$$

In computing an orbit the *Mean* Anomaly M is known for any given day. Then by Kepler's Equation E is found

$$M = E - e \sin E \quad (2)$$

E being an arc and $e \sin E$ a linear quantity the latter term must be divided by sin 1″. Then

$$\left.\begin{aligned} \frac{r \cos v}{a} &= \cos E - e \\ \frac{r \sin v}{a} &= \sqrt{1 - e^2} \sin E \end{aligned}\right\} \quad (3)$$

We may also use

$$r = a(1 - e \cos E)$$

by which v and r may be computed and tabulated. Then by Kepler's Equation, the equation of the Center $v - M$ becomes known. The above equations can be combined into a series by which this quantity is usually computed and tabulated with M as the argument.

We also have as follows E being here the Equation of the Center:

$$v = M + E$$
$$\gamma = v + \pi$$
$$u = \gamma - \theta$$

Also $$\sin \beta_0 = \sin i \sin u.$$

by which the latitude may be computed and tabulated.

To recapitulate, the above formulæ in the sequence they necessarily occur in the Tables we have M the Mean Anomaly which may be given either in arc, of which the period will be 360°, or in days of which the period is the periodic time of the planet. In the Tables of Uranus and Neptune M is given in units, each one representing 36′ of the planet's motion the period being 600 representing 360°. In all the other tables M is given in days, increasing one unit for each day of the year.

The perturbations we have not referred to above. They must be taken out of the tables by various arguments as directed in the precept to each table, added together and interpolated for the interval of the rest of the work.

The secular variations are the small changes of the elements, the change being given for one century, they must be multiplied by the fraction of the century elapsed since the Epoch of the Tables. l_0, θ_0, π_0, are the quantities tabulated for the beginning of the year, while Δl, $\Delta\theta$, $\Delta\pi$ are their changes for any other day of the year, usually designated as "Motion for the days" E, r, β_0 are tabulated values for convenient intervals of their arguments.*

After finding the arguments it is preferable to compute the perturbations next and then to combine the three small terms, perturbations, secular variation and proportional part of the equation of the center. Then proceed as follows:

3. Sequence of Formulæ in the Tables.

M Mean Anomaly assumed at pleasure. Argument for r_0 and for E the Equa. Center (also called g, M, H, K, or N, in the Tables).

l_0 = Mean Longitude for the beginning of the year.

γ = Longitude in orbit.

$$= l_0 + \Delta l + (\text{Pert} + \text{sec. var.} + pp) + E \qquad (4)$$

$$\theta = \theta_0 + \Delta\theta \qquad (5)$$

$u = \gamma - \theta$ Argument for the Latitude and Re (6)

Heliocentric Longitude, Mean Equinox for Nautical Almanac, is then

$$l = \gamma + (Re + pp + \text{sec. var.}) \qquad (7)$$

In the Tables of Jupiter and Saturn

$$\text{Fundamental argument} = \text{I} + \Delta\text{I} + \text{Pert} + \text{cor for true day} \qquad (8)$$

$$l = (v + Re)\ \chi\ pp + (\pi + ht) + \Delta\,(\pi + ht) \qquad (9)$$

v being the true anomaly.

* The notation here used is employed to describe the quantities. Some of the characters but not all appear in the printed Tables.

The Radius Vector

$$r = r_0 + pp + \text{sec. var.} + \text{pert.} \qquad (10)$$

$$\beta = \beta_0 + pp + \text{sec. var.} + \text{pert.} \qquad (11)$$

For Uranus and Neptune β_0 is not tabulated but must be computed by the formula

$$\sin \beta_0 = \sin i \sin u. \qquad (12)$$

For computing an ephemeris, the true longitude

$$L = l + \text{Equation of the Equinoxes} \qquad (13)$$

and the reduction to the orbit for Nautical Almanac

$$R_0 = -Re. \qquad (14)$$

The terms in the second members of the above equations, (except those derived from previous equations) are to be taken from the Tables.

4. DESCRIPTION OF THE TABLES. In the Tables of the Planets by Professor Newcomb and Dr. Hill, the mean anomaly is denoted by the letter g with which the double entry tables are entered; but the other perturbations and the equation of the center, etc., are taken out by another argument such that the equation of the center shall be 0° 0′ 0″.00 at the aphelion. These arguments are

Sun	$M = g + 5.37$
Mercury	$H = g + 1.015325$
Venus	$K = g + 0.649577$
Mars	$N = g + 0.502176$
Jupiter and Saturn,	Argument for g is l
Uranus and Neptune.	" " g " the date

The arguments $MHKN$ are tabulated, from which g is then found. They are the principal arguments and most frequent to occur.

These Tables, according to the method of using them, may be divided into three groups, though in some respects there exists a general similarity between them.

The first group comprises the Sun, Mercury, Venus and Mars, whose motions are so rapid that the first two named must be generally computed for every day of the year, and the two latter for every second day, though the perturbations are tabulated for four, eight, or twelve days.

The second group, the preparation of which was assigned by Professor Newcomb to Dr. Hill includes Jupiter and Saturn in which the perturbations are computed by the method of Hansen and applied to the Mean Anomaly which then is called *Fundamental Argument*, and gives the true anomaly plus the Reduc-

tion to the Ecliptic. The perturbations of Jupiter are tabulated for every forty days and those for Saturn every eighty days or sometimes multiples or fractions thereof but the rest of the work from the tables is carried on for every twentieth day for each planet, for which interval the longitude, latitude and radius vector result.

The third group includes the planets Uranus and Neptune. The intervals of the computation are arbitrary. The perturbations here consist of coefficients which are to be multiplied by the sines and cosines of various angles and their multiples. No tables for the latitude are given, which must therefore be computed.

As the perturbations are naturally positive or negative, a certain constant is usually added to make each table *positive*, and the sum of these constants, then deducted from the equation of the center, logarithm of the radius vector or latitude as the case may be. But no constant is added to the tables of Uranus and Neptune.

Isolated dates may be taken out from these tables for any given time, and the work for Mercury would not be much more difficult than that for Neptune, nor would it take much longer; but to take out an ephemeris for one year, is quite a different matter. The time required for the writer of this article to take out an ephemeris of Neptune for three years is sixteen hours or less than six hours for one year. But Mercury requires at least 125 hours for one year's ephemeris.

5. THE FIRST GROUP, THE SUN, MERCURY, VENUS, MARS. These may be illustrated by an example from Mars. The Precept given in the tables is clear and should be followed in connection with what is given here. For the first date of the year to be computed 1909, January 1, Tables II, III and V, we have:—

	N	*g*	*I*			*θ*		
1909	462.28795		216°	20′	3.08	48	51	19.2
Long period	+ 50				.96			0.0
For Day	1.		0	31	26.66			0.1
Jan. 1	463.28845	462.786	216	51	30.70	48	51	19.3

g is the mean anomaly of the planet increasing one unit for each day. It is found from *N* by the formula $g = N - 0.502176$. The arguments I to V are constant during one revolution of the planet, but when the period of *N* is reached it must be deducted from *N* and the *increments*, Table VI, added to the arguments I to V.

The arguments *A* to *G* are next to be found Tables II, III, VI in-

creasing one unit for each day of the year, and periods are to be deducted when passed, Table VI. They present no difficulty.

. With arguments I, V, Tables VII to XI must be entered but as it is difficult to interpolate for both arguments the quantities must be taken for the values of g there given interpolating in the vertical columns for I to V. The sum is there to be interpolated for the true value of g. The work is as follows:

1909	I	II	III	IV	V	Sum		Cor-rection		1909	E	Pert.
g	9.78	175.29	50.076	898	7.2							
468	130	494	1726	678	17	3045		−26	+1	Jan.7 3046		+25
480	130	478	1753	682	18	3061	+16	28	0	19 3061	+15	29
492	130	460	1757	684	18	3049	−12	−36	−2	31 3047	−14	+37
							−48				−51	

The sum must be differenced to find mistakes and then be interpolated for the true value of g.

On Jan. 1		$g = 462.786$
7	True argument	468.786
	Tabular "	468 006
	Difference	0.786

so that if all these values are interpolated forward for this interval the perturbations will be given correctly for the assumed dates. As the interval of the tables is twelve days and 0.786 is a fraction of one day the factor for interpolating is

$$+\frac{0.786}{12.000} = +0.065$$

The first difference then gives a correction of +01, the second is 00 and the third —.02 or nearly —.03. And the value of g compared with the first computed value gives us the date above given. Second differences should be used if necessary.

These perturbations must now be interpolated to some closer interval, say eight or four days, and the quantities for tables XII to XVIII Arguments A to G, taken out, and added to the previous. The secular variations table XIX is to be multiplied by the fractions of a century since 1900.0 and also added. The computer will need to provide himself with the days of a year, in decimals of one year February 20 is 0.14 and the decimal of a century for 1909, February 20 is 0.0914.

The proportional part of the equation of the center may also be found and added here. We have as follows:

1909, Jan. 3 N	465.28845
Table XX gives	465.28
Difference,	.00845

Interval of table .02, factor for interpolation 0.422. Tabular difference, —3.″54. Proportional part, —1.″49.

The sum of all the above quantities must now be interpolated, for every second day for which interval the rest of the week for the longitude is carried on.

To add several quantities together, the most natural way is to place them in columns and add them vertically and it suffices very well when the columns are few as in the computation of eclipses and occultations and where only four or five place logarithms are employed, but where there are many such columns and the quantities few to be added, the method preferred by expert computers especially when using seven or eight place logarithms, is to place the dates in a column on the margin of the sheet, with the precepts of the formulæ at the head of the columns, and the work is then performed horizontally. For Mars the 190 dates will then form the first column, and the next column to the dates will be quantities previously found which are the terms (pert + sec. var. + *pp*) of formula (4).

Argument *N* may be written every twenty or thirty lines on these pages merely as a guide—the only argument that need be so written. The equation of the center is taken out next from every other column and the remaining terms of equation (4) added, giving γ the longitude in orbit. They cannot all be added at once, as the equation of the center may be negative. The remaining formulæ (5) to (7) are to be followed taking the several quantities from the tables giving the longitude. The work for the latitude and radius vector is similar to that for the longitude.

Mercury, Venus. The use of the tables for these planets is very similar to that for Mars. After getting the perturbations the principal work for Venus, as for Mars, is computed for every second day, and the eccentricity of the orbit being small,—the smallest of the solar system, renders the work comparatively easy. Mercury on the contrary has the greatest eccentricity of any of the planets and this combined with its rapid motion renders it by far the most difficult of all.

The Sun. The system of the Earth and Moon are here properly regarded as a planet moving about the Sun; but the longitude has 180° added to it which then gives the Sun's longitude. Nearly all of the work from the tables must be carried on for every day, not on account of its being difficult but because of the short period of the lunar perturbations. The Earth and Moon revolve about their common center of gravity, so that when the Moon is above the ecliptic the Earth is below causing the Sun to have a small positive latitude. It hardly exceeds half a second of arc but the perturbations may double it or change its sign. The formula for this is as follows:

$$\text{Sun's lat.} = \frac{1''}{81.45 \sin 1''} \cdot \frac{\pi^1}{\pi} \sin \beta \qquad (15)$$

in which π' and π are the parallaxes of the Sun and Moon respectively and and β the Moon's latitude. The formula is also given in the tables of the Sun page 17.

It is natural to regard the center of the Earth as the center of this planet moving about the Sun; especially as astronomical observations of the planets are reduced to the center of the Earth. But this is not the true center of the planet, which is the common center of gravity of the Earth and Moon. And these reductions of the planets would give erroneous positions, were it not that this is taken account of in the solar tables. The displacement of the Earth's center above and below the ecliptic, as we have seen above, is the Sun's latitude with a contrary sign, and the lateral displacement,—that in longitude, is taken account of in Professor Newcomb's Table principally by the argument D which is the Moon's age, and which also gives a correction for the distance from the Sun, as well as for the longitude. When the Moon is in syzygy the whole effect falls upon the distance.

Regarding the Sun it is interesting to note that the equation of time is only a transformation of the equation of the center. We have the Sun's true anomaly

$$v = M + E$$

M being the mean anomaly and E the equation of the center. Also

Sun's true longitude	$\lambda = v + \pi$	
Sun's mean longitude	$L = M + \pi$	
Whence	$\lambda = M + E + \pi$	
	$= L + E$	
Sun's true R. A.	$A = \gamma + Re$	
	$= L + E + Re$	
Whence	$A - L = E + Re$	(16)

A—L is here the equation of time and Re the reduction by that formula from the ecliptic to the equator. This formula which is given in Brünnow's Astronomy is said to be only approximate, the correct value being the mean longitude minus the true right ascension.

6. The Second Group, Jupiter and Saturn. The method of using these two tables is so similar to that of Mars that no example of the earlier part of the work is necessary, it may however be remarked that the motion of Saturn being the slower, the intervals of the computation may be greater than those of Jupiter. The perturbations may be taken out for intervals not

greater than eighty days for Saturn, and forty days for Jupiter. As argument I occurs frequently it may be an advantage to compute the perturbations for tabulated values of this argument, finally reducing the result for the true value. Moreover all of the arguments might also be reduced to the tabular values of argument I and used in the same manner. The sum of the perturbations is to be interpolated to an interval not exceeding twenty days for each planet and added to argument I which is now called the *Fundamental Argument*.

With this argument; the tables give $v + Re$ and "log $D.M$". This latter gives the proportional part; but it must be interpolated for half the interval before being used; and to avoid error it is imperative that log $D.M.$ should be taken for the shorter interval, whether the interpolation is forward or back. The computer should work closely here, since neglect of these two precepts may cause errors larger or smaller without their being perceived. Table I of each planet then gives the longitude of the perihelion $\pi = \pi_0 + ht$, and table IV its motion for the days. Hence the longitude l by equation nine above given.

The radius vector and latitude can readily be found by the precepts given in the tables; the work in some respects is similar to that for the longitude, and likewise follows the Sequence of Formulæ; equations ten and eleven.

For these two planets the secular variation is taken account of in the Tables but not as a separate term.

THE THIRD GROUP, URANUS AND NEPTUNE. Table I for each of these planets, gives the quantities l, g, θ, and the arguments for every fourth year, the succeeding tables then give their changes for the months and days. It saves time to take out three or four at once, provided the computer expects to make use of so many years' work. Multiples of g are next to be found. The tables give the coefficients to be multiplied by the sines and cosines to form the following expression

$$vc0 + vs1 \sin g + vc1 \cos g + vs2 \sin 2g + vc2 \cos 2g + \text{etc}$$

up to the fifth multiple. Signs must be carefully observed, as the terms and factors result either + or — and change frequently. The several quantities taken from the tables are combined according to the sequence of *Formulæ for Tables* given above.

The radius vector and its perturbations are found in a similar manner to the longitudes. The latitude however must be found by the formula 12

$$\sin \beta_0 = \sin i \sin u.$$

The tables give the values of i and sin i, and u is found from the usual formula (6) $u = \gamma - \theta$. Finally the latitude is given by Formula (11).

THE GYROSCOPE. II.

F. J. B. CORDEIRO.

For Popular Astronomy.

Let us suppose a gyroscope as in Figure 8 such that it spins on its axis *WOG* within a ring which is pivoted on a horizontal axis *HOH'*, and that this ring moves within another ring which is pivoted vertically about an axis *VV'*. A counterbalancing weight *w* abolishes gravity so that it is free to move in all directions under the action of no forces except such initial impulses as are given it. Let us set the gyroscope spinning and then give it an initial

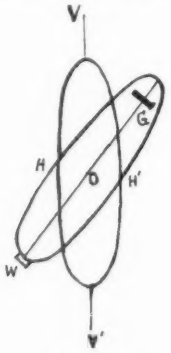


Figure 8

angular velocity Ω about the vertical axis *VV'*. In our previous examination of the motion of a gyroscope under the action of no forces, we saw that under such conditions the gyroscope selected for itself an invariable line about which its axis described a circular cone and that this invariable line was determined by the condition that $C \tan \gamma = A \tan \iota$, where γ was the angle between the axis of the gyroscope and the invariable line and ι was the angle between the axis of the gyroscope and the instantaneous axis.

In the present case if Ω satisfies these conditions, then the gyroscope will continue to circle about the vertical axis at a constant height. But if Ω does not satisfy this condition, then since, as we may say, the invariable line *VV'* is selected for the gyroscope beforehand, it will have to accomodate itself to it. That is, it will have to rise or fall until the angular velocities ω and Ω

satisfy our condition. We can look at this from another point of view. As the gyroscope circles around the vertical axis, centrifugal forces will be brought into play which will tend to make the gyroscope place its axis horizontally, and this would be the result if the gyroscope were not spinning. But we know that at the same time gyroscopic forces are set up, which, if the spin and the turn are both counter-clockwise, will urge the gyroscope towards the vertical axis. In a position of equilibrium, therefore, these forces which tend to turn the gyroscope in opposite directions about the axis HH' must be equal.

Now the turning component of the centrifugal force or the component at right angles to the axis of the gyroscope is easily seen to be

$$M.OG.\ \sin\gamma.\ \cos\gamma.\ \Omega^2$$

and the component of the gyroscopic force at right angles to this axis is, as we know,

$$M.\ \frac{k^2\ \omega\ \Omega\ \sin\gamma}{OG}.$$

Equating these forces we find that

$$\overline{OG}^2 \cos\gamma\ \Omega = k^2\omega. \qquad \text{But} \quad \Omega\ \sin\gamma = \omega\ \tan\iota.$$

Consequently $C\ \tan\gamma = A\ \tan\iota$, which is our original condition. If these forces are not equal at the instant of starting, then the gyroscope will move in the direction of the preponderating force, until, with constantly diminishing acceleration it reaches the position of equilibrium. But owing to its inertia it can not stop here, but will be carried beyond. Now a reversed force, gradually increasing, will finally cause it to stop and eventually bring it back to its position of equilibrium. It will thus continually oscillate about the position of equilibrium, approaching towards and receding from the vertical axis.

We shall define a storm as a rotating mass of air. This definition covers all storms with which we are familiar. Why a disturbance of the atmosphere tends to develop into circular motion, or rather re-entrant motion, we shall not consider here. The reader is referred to the article "Tropical Hurricanes," in the *Bulletin of the American Geographical Society*, No. 3, 1900, and to the "Problem of the Cyclone," in the *Monthly Weather Review* for November, 1903; also to the article "Gyroscopes and Cyclones," in the *American Journal of Mathematics*, Vol. XXVIII, No. 3.

Suffice it here to say that it is inevitable on a rotating sphere. Not all storms have the same degree of severity,—rotational

energy—or extent. The atmospheric disturbances that sweep across the United States are often very extended and have hardly rotational energy enough to be called storms, but still they are rotational and translational phenomena. On the other hand the extreme rotational energy of a West Indian storm is specially designated by the term hurricane or cyclone. The wind sweeps here more or less spirally about or towards a center, called the eye of the storm, with exceptional fury.

Now if we direct a stream of water through a series of tubes curled in the shape of spirals or circles about a common center so that we have a mass of rotating matter, the system becomes for all dynamical purposes a gyroscope. That is, if we turn this rotating mass about some other axis than its own, it develops gyroscopic forces.

The matter can be put to the test very easily. Suppose we have, as in Figure 9, a circular disk rigidly attached to a rod, passing through its center. The disk it will be understood cannot rotate on the rod but instead we lead a tube along the rod

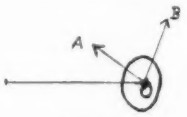


FIGURE 9

to the center of the disk and then radially to the circumference, and then after passing it several times around the circumference we bring it back to the center and then along the rod. Now if we allow a current of water to flow rapidly through the tube and then holding the rod in our hands give it a sudden turn horizontally in the direction *OA*, we shall feel a violent jerk upwards in the direction *OB*. That is, it will do so if the water is flowing in a counter-clockwise direction, as we already know. If flowing in the opposite direction, the jerk would be downwards. Here the disk and tubes do not rotate, but the water does. All that is essential for a gyroscope is, of course, a rotating mass and it does not matter whether this mass is solid, liquid or gaseous. If we forced a current of air through our tubes swiftly, the result would be the same. In any case we could calculate easily what the resulting gyroscopic force would be. It depends simply upon the rotational energies which again depend upon the masses and angular velocities.

Now in a storm we have precisely such a rotating mass of air, only the masses here are enormous, being measured by thousands

of tons and the velocities are very great. In our experimental water gyroscope we were forced to form the stream lines by artificial constraints, viz., the tubes, but in a storm the stream lines form themselves and maintain their relative positions naturally.

We are now in a position to understand the motion of a storm after it has once formed. Let us suppose that a violent hurricane has developed at some point in the West Indies. Referring back to Figure 8, we see that first of all the centrifugal forces due to the Earth's rotation on its axis and the gyroscopic forces of the cyclone will contend for the mastery. These, and frictional forces, due to the friction of the under side of the cyclone on the surface of the Earth are the only forces that come into play. For the time being we shall disregard friction. We can easily surmise that in a low latitude and with a violent hurricane, the gyroscopic forces will overpower the centrifugal. The cyclone therefore moves rapidly and bodily, to the north. This is because all storms in the northern hemisphere move in a counter-clockwise direction or in the same direction as the Earth. On the other hand storms in the southern hemisphere always move in a clockwise direction as does the Earth there. The result is that in either case there is a motion of the cyclone towards the respective pole.

The storm therefore will travel northwards until it reaches its position of equilibrium as in our gyroscope experiment. If its northward velocity could be stopped at this point it would remain on the same parallel of latitude, i.e., the axis of the Earth would become its invariable line.

Further if the elements of which it was originally composed had a moment of momentum about the Earth's axis corresponding to the velocity of the surface of the Earth at this particular point, it would remain stationary relatively to the Earth. If greater, it would travel along this parallel of latitude; if less it would travel in the opposite or westward direction, keeping al-

FIGURE 10

ways the same latitude. But owing to its inertia we have seen that it would not stop at its position of equilibrium, but would oscillate backwards and forwards across it. Now if this motion were developed upon a plane surface the path traced by the storm would be a wavy line with the parallel of equilibrium running through it like an axis. See Figure 10.

But the velocity of the Earth varies with the latitude and very rapidly in high latitudes. The consequence is that developed upon such a moving surface as that of the Earth the path of a storm will appear as in Figure 11.

FIGURE 11

We have been led to the form of this path by purely theoretical considerations. Now the paths of numbers of storms in high latitudes which have been charted exhibit exactly this shape. We should expect that the parallel of equilibrium of a violent storm would be in a high latitude and such we find to be the case. Now if the energy of such a storm could be constantly maintained we might expect that it would continue on forever. Generally the energy is dissipated in little more than a week though they often last two weeks or longer. Abercromby, of the British Meteorological Service, has recorded a storm which he traced from its origin in the Philippines, northward to Japan, thence across the Pacific Ocean, over Northern America and the North Atlantic Ocean, across Europe, until it finally died out on the Steppes of Siberia, having thus nearly encircled the globe. The Galveston hurricane, after crossing the United States and emerging through the St. Lawrence valley on the Atlantic, caused havoc in Iceland two weeks after it had destroyed Galveston.

Let us now consider the frictional couple caused by the rotating mass of air. We shall suppose that the rotational energy of the cyclone is kept constant by fresh supplies of force. Now the total rotational energy about the Earth's axis is composed of two parts; the most important part being the bodily rotation of the cyclone about this axis and the other being the component about this axis of the cyclonic rotation. Now the frictional couple is exerted always in a contrary direction so that it continually decreases the total moment of momentum of the cyclone. Since we have supposed the cyclonic energy of rotation kept constant, this must be at the expense of the moment about the Earth's axis. And in fact we find that this is continually decreasing. As long as the velocity of this moment is less than that of the corresponding point on the Earth's surface, the cyclone will travel to the westward. As the cyclone gets to the northward where the Earth's velocity is rapidly decreasing, a point will be reached

where the velocities become equal. This is the point of recurvation, so-called. Beyond this the Earth's velocity decreases more rapidly than that of the cyclone and the consequence is that the cyclone travels to the eastward.

FIGURE 12

The path of a cyclone is well represented in Figure 12.

As will be seen it somewhat resembles a parabola projected upon a spherical surface.

These paths are extremely regular and year after year they trace out the same curves. It will be seen that by observing two positions of a cyclone we may thus calculate θ and $\dot{\psi}$ and from these compute the moment of momentum of the cyclone thereby being able to predict approximately its position at some future time. The author has thus been able from an examination of old charted paths to forecast the position several days in advance. Of course our formulæ depend upon the rotational energy's remaining constant and this will often not be the case even approximately, if a too long period is allowed to elapse. It is probable however that in time such forecasting will be made for several days ahead, at least, with considerable accuracy.

The sweep of a gyroscope about its point of support is called its precession, while the cycloidal undulations are called its nutations or noddings. We now come to consider the phenomenon known as the Precession of the Equinoxes. This is a gyroscopic phenomenon, for as we shall soon see, the Earth is a gyroscope. If the Earth were a perfect homogeneous sphere the attractions of the Sun and Moon would not be able to produce gyroscopic motion, but the Earth is a spheroid with a marked preponderance of matter about the equator. The result is that the pull of the Sun does not always act in a line through the Earth's center

of inertia or symmetry, but acts through varying lines according to his position.

We can exemplify this by the accompanying figure. Let us suppose that four equal bodies are attached to the extremities of

FIGURE 13*

the rectangular arms k, k', and are attracted by the Sun, while the center is fixed, but free to turn in the plane of the page.

If the arms are of equal length there will be no turning, but if k is longer than k' this will not be the case.

Let S represent the mass of the Sun considered as an attracting point and at a great distance. Let d_1, d_2, d_3, d_4 represent respectively the distances of the four bodies from the Sun. Now the attraction of the Sun on the body 1 will be $\frac{MS}{d_1^2}$ and the turning moment of this attraction about the fixed center will be

$$\frac{MS}{d_1^2} \cdot k \sin \delta$$

where δ represents the angle $SO1$ and M is the mass of one of the bodies. The turning moment of the attraction of the Sun on the body 2 will be in the opposite direction and will be equal to

$$\frac{MS}{d_2^2} k \sin \delta.$$

Likewise the turning moment on 3 will be

$$\frac{MSk'}{d_3^2} \cos \delta,$$

and on 4,

$$\frac{MSk'}{d_4^2} \cos \delta.$$

The sum or the resulting turning moment is

$$MSk \sin \delta \left(\frac{1}{d_1^2} - \frac{1}{d_2^2} \right) - MSk^1 \cos \delta \left(\frac{1}{d_3^2} - \frac{1}{d_4^2} \right) \quad \text{or}$$

$$MSk \sin \delta \left(\frac{d_2^2 - d_1^2}{d_1^2 d_2^2} \right) - Mk' \cos \delta \left(\frac{d_4^2 - d_3^2}{d_3^2 d_4^2} \right).$$

* The lettering on Figure 13 should read k and k' instead of h and h'.

But $d_1^2\, d_2^2$ and $d_3^2\, d_4^2$ are practically equal to D^4 where D represents the distance of the Sun from the center:

$$d_2^2 - d_1^2$$

can be written

$$(d_2 - d_1)\ \ (d_2 + d_1)$$

and

$$d_4^2 - d_3^2 = (d_4 - d_3)\ (d_4 + d_3).$$

Now $d_2 + d_1$ and $d_4 + d_3$ can be considered as equal to $2D$ and

$$d_2 - d_1 = 2\ k \cos \delta$$

while

$$d_4 - d_3 = 2\ k' \sin \delta.$$

Consequently our resulting turning moment is

$$4.\ \frac{S \sin \delta . \cos \delta}{D^3}\ (Mk^2 - Mk'^2)$$

In the same manner owing to the protuberance of the equator the Sun exerts a turning moment whenever it is not in the plane of the equator, and it is found for the distribution of matter in a spheroid, that this turning moment is equal to

$$\frac{3 . S \sin \delta . \cos \delta}{D^3}\ (Mk^2 - Mk'^2)$$

where δ represents the declination of the Sun or its angular distance from the plane of the equator, while Mk^2 and Mk'^2 are the moments of inertia about the polar and equatorial axis respectively.

Now as the Earth is revolving on its axis, we know that this turning moment will not take effect in the direction in which it acts, at least not wholly. Its tendency is to bring the planes of the equator and ecliptic into coincidence, but as soon as the Earth starts to obey this pull, a gyroscopic couple is set up acting in a plane at right angles to the Sun's couple, and passing through the axis of the Earth. The result is that the Earth's axis describes a cone about an axis passing through the Earth's center, perpendicular to the ecliptic.

Now the Earth is only twice a year in a position where a plane passing through its axis and the Sun is perpendicular to the ecliptic. At other times such a plane is oblique to the ecliptic, so that the Earth's axis will not always maintain a constant inclination to the ecliptic. But for one of these oblique positions there is always another corresponding one in the orbit where the axis will be urged in a contrary direction, so that the average effect of the Sun's turning moment is to keep the axis at an average constant inclination to the ecliptic. As we have said, the re-

sult is that the axis of the Earth circles slowly around the axis of the ecliptic, performing the circuit in something like 26,000 years.

It will now be clearly seen that the line of intersection of the equatorial and ecliptic planes, or their nodes, so-called, or the equinoctial positions, move backward over the Earth's orbit, so that from one equinoctial position to another is less than a year, as a matter of fact by something like 50″ of arc. That is, the pole of the Earth moves something like this amount about the pole of precession, which is the pole of the ecliptic.

This motion is necessarily slow because the turning moment of the Sun is so feeble. If the Moon moved in the plane of the ecliptic, the joint precessional moment of the two bodies would be

$$3\left(C-A\right)\sin\delta\cos\delta\left(\frac{S}{D^3}+\frac{M}{D_1^3}\right)$$

where M represents the mass of the Moon, and D_1 her distance from the Earth. It is easily seen by applying this formula, that owing to her lesser distance, the Moon's precessional effect is more than twice as great as that of the Sun.

We have seen the time of executing a small cycloidal undulation, or nodding, was independent of the actuating force and equal to

$$\frac{2\pi A}{C\omega}$$

If we take an hour as our unit of time, we see that $\omega = .232$ or the time of an undulation is $\frac{24 A}{C}$. Now we have reason to believe that $\frac{A}{C}$ is nearly .99681. Consequently the time of one of these undulations is very nearly a day.

Since the dip of the undulation is proportional to the actuating force and this is relatively to the Earth's angular velocity extremely minute it is practically too small to be calculated. With the Sun and the Moon at a constant declination, therefore, the precession would be practically an even line.

But the fact is that the Moon does not move in the ecliptic; but in an orbit inclined about five degrees to the ecliptic. Further the plane of this orbit does not remain in a fixed position but is constantly varying. The pole of the Moon's orbit describes a circle around the pole of the ecliptic at a distance of five degrees, in a regular period of a little less than nineteen years in a retrograde direction, i. e., contrary to the planetary motions.

This movement of the pole of the Moon's orbit about the pole

of the ecliptic is easily seen to be caused by the Sun's attraction on the Moon and is nothing more than a gyroscopic precessional motion. The difference of the Sun's attraction when the Moon is nearest and farthest from it, results in a couple tending to bring the Moon's orbit into coincidence with the ecliptic, just as the difference of the Sun's pull on the nearer and farther equatorial protuberance of the Earth produces a like couple and the resulting precession.

Since the Moon's mass is much greater than the mass of the Earth's protuberance, and the leverage is very much increased, the resulting couple, and therefore the precession, is much greater in the case of the Moon. Of course the direction of this precession must be retrograde as in the case of the Earth.

A little further consideration, which we have not space to go into more fully will show the reader that this precessional motion of the Moon's orbit will set up gyroscopic forces which will force the Moon's axis of rotation to maintain a fixed position with reference to the orbital plane. In other words, the axis about which the Moon rotates moves with the orbital plane as if it were rigidly attached to it. Further its position with reference to this orbital plane must be such that the Moon's equatorial plane presents itself to the Earth edgewise whenever the Moon is at one of her nodes or the points where her orbit crosses the ecliptic. Observation shows this to be precisely a fact.

The consequence is that while the Sun strives to effect its precession about the pole of the ecliptic, the Moon strives to have the precession accomplished about the pole of her orbit, and as her precessional moment is about twice as great as that of the Sun, she has decidedly the best of it. From this cause there is a perturbation in the movement of the Earth's pole and instead of describing a smooth line it is marked by undulations which have a nineteen year period.

Still, as in the vast total period of about 26,000 years the average effect would not be altered by this trifling nineteen year undulation, we might consider it as unimportant. It will be well to call the reader's attention to the disturbances caused by the change of declination of these two bodies. At two points in every revolution they have no declination with a maximum between times. The result is that there is a half-yearly and a half-monthly perturbation which are usually spoken of as the solar and lunar nutations. The writer has used the term nutation above in an entirely different sense viz., the true gyroscopic nutation.

In order to have a perfectly clear idea of the precessional motion of the Earth, let us now review some of the ground we have gone over. Let us suppose the spheroid EOE' to represent the Earth, with EOE' and POP' the equatorial and polar diameters respectively.

We have seen that the attraction of the Sun will tend to turn the Earth about an axis through the point O perpendicular to the page.

If the Earth was not rotating, it would in fact bring the equatorial plane into coincidence with the ecliptic. But since the Earth is rotating, the result is that the Earth starts to turn about the axis EE' in the plane of the page, and we know that the moment of the couple due to the Sun's attraction is

$$\frac{3S\,(C-A)\sin\delta\cos\delta}{D^3} = C\omega\dot{\phi}$$

where $\dot{\phi}$ is the angular velocity of turning about the axis EE'.

The result is that the polar axis of the Earth would come eventually into coincidence with an axis perpendicular to the page. But if the Sun kept moving about the perpendicular line

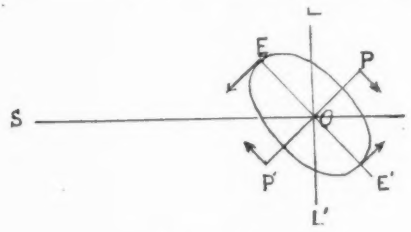


FIGURE 14

LOL' so as to keep always in the plane LOP, then OP would always maintain a constant inclination to the ecliptic and would describe a cone about LOL'. This is practically what happens owing to the revolution of the Earth in its orbit.

If, in Figure 15, 1 represents an equinoctial position where a rotating disk would be seen from the Sun edgewise, there will here be no precessional effect.

But in the other two positions of the diagram, the disk when viewed from the Sun would have the appearance as drawn in the figure.

Let us now follow the precessional effect from 1 to 2. A plane passed through the Sun and the polar axis would in 1 be inclined 23° 28′ to the ecliptic, while in 2 it would be perpendicular to

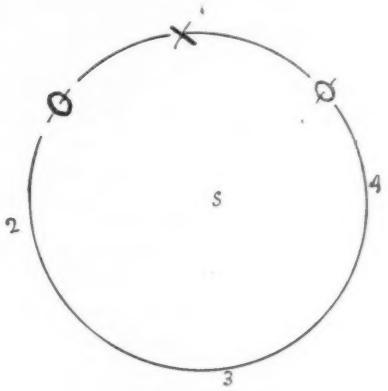


FIGURE 15

the ecliptic. Between these two positions there is every intermediate angle. Now the turning moment between these two positions will be exerted about the line in which our Sun-polar axis plane cuts the disk as an axis and perpendicular to this plane and upwards. That is, from 1 to 2 the inclination of the axis to the ecliptic is continually being raised. From 2 to 3 it is again lowered to its original level at 1. From 3 to 4 it is again raised and from 4 to 1 again lowered, so that 1 and 3 are the low points and 2 and 4 are the high points.

A little consideration will also show that besides this vertical motion of the axis there are also displacements in the direction 1, 3 and the direction 2, 4. The displacement from 1 to 3 is continuous throughout the whole orbit, that is it never changes direction. At 1 and 3 it becomes zero, but is a maximum at 2 and 4. The average amount of this motion is the precession.

The 2, 4 motion, or that across the page, decreases from 1 to 2 where it becomes zero and then increases from 2 to 3. It is in the first quadrant in the direction S, 2, and in the second quadrant in the direction 2, S. These motions compounded are the same as if the pole described a minute ellipse about a point moving with a constant, or the average, processional motion.

The long axis of this ellipse is in the direction of precessional motion, the short axis perpendicular to it. This small ellipse is described twice in a complete revolution of the Earth. For the Sun, its long axis amounts to 1".23 and the short axis to ."53. Similarly the Moon produces a half monthly perturbation, or two ellipses are described about the mean processional motion due

to the Moon every month. This ellipse however is only about one-sixth that produced by the Sun. These perturbations are known generally as the Sun's and Moon's nutations. It should be borne in mind that they are not true gyroscopic nutations.

The reader need not pay any special attention to these slight perturbations, as they are of no importance. The essential point is to see clearly that the effect of a single attracting body, such as the Sun, is to produce a constant precessional rotation of the pole of the Earth about the pole of the orbit of the attracting body, and that the polar axis must maintain a constant average inclination to the ecliptic.

Referring to Figure 14, we see that we could represent the precession by a constant rotation about the axis LOL' with angular velocity $\dot{\psi}$ (equal to $\phi \sin \delta$). If this rotation is in a retrograde direction, that is opposite to planetary motion, its gyroscopic couple would exactly balance the Sun's attractional turning couple and the motion would be steady. Since the Sun's average turning moment is that due to a constant declination equal to half its maximum, we could write

$$\frac{3S\,(C-A)\sin\delta\sin\frac{\delta}{2}}{2D} = C\,\omega\,\dot{\psi}.$$

We now come to an extremely important perturbation, viz., that due to the shifting of the Moon's orbit. We have seen that the Moon's orbit is inclined at an angle of five degrees to the ecliptic, and that the pole of this orbit describes a circle in a retrograde direction about the pole of the ecliptic in 18.6 years.

The result is that at two equi-distant periods the inclination of the Moon's orbit to the equatorial plane acquires two extremes, viz., a maximum and a minimum.

In Figure 16, if OS and OL represent the plane of the ecliptic

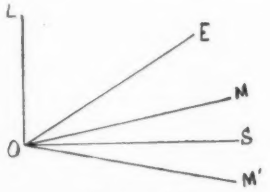


FIGURE 16

and its axis respectively and OE the inclination of the Earth's equator then OM and OM' represent the two extreme inclinations of the Moon's orbit.

If the Moon moved always in the ecliptic it would be very easy to compound its precessional effect with that of the Sun; it would be a simple case of addition.

With the same declination the Sun's prece-sional effect is .451 that of the Moon's or less than half, as is easily seen from the formula above. This is because, while the Sun's mass is 26,325,000 times that of the Moon, its distance is 387 times as great.

The mass divided by the cube of the distance is therefore only .451 that of the corresponding amount in the case of the Moon. Now, owing to its revolution, the average effect of an attracting body is half the maximum declination. Consequently the factor $\sin \delta \cos \delta$ is for the Sun .19911, and for the Moon's minimum position .15837, while for the Moon's maximum position it is .23832.

The precessional effect, then, of the Sun, and of the Moon in her two extreme positions would be proportional to the following numbers:

For the Sun	.0898
For Moon's minimum position	.15837
For Moon's maximum position	.23832

Therefore the Moon's minimum precessional effect is 1.76 times that of the Sun and her maximum precessional effect is 2.65 times that of the Sun. But this is not all. In the position of minimum inclination, the compromise precessional pole falls between the poles of the respective orbits on one side, while in the maximum position it falls on the other side of the pole of the ecliptic but by a greater distance. During the nineteen year cycle, therefore, the compromise pole is moving about the pole of the ecliptic, in a retrograde direction, in an oval. In fact it is an ellipse, one focus of which is occupied by the pole of the ecliptic.*

The precessional rotation at any instant therefore takes place

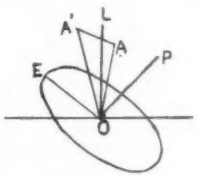


FIGURE 17

about an axis which does not coincide with *OL*, but which revolves about *OL* in a nineteen year period. In Figure 17, *OA'*

* Query. How far are these Moon strains of the earth's crust, varying in intensity and direction, responsible for earthquakes?

represents the maximum precessional axis both in position and in magnitude by its length, while OA similarly represents the minimum axis. In the Moon's maximum position the Earth acquires a maximum rotation about the axis OA' such that its gyroscopic couple is exactly counterbalanced by the attractional turning couple of the Sun and Moon. In the minimum position of the Moon a rotation about the axis OA is required of such magnitude as to exactly balance the weakened couple of attraction. For equilibrium in the minimum position therefore the surplus rotation that the Earth possessed in the maximum position must be destroyed.

The rotation about OA' is equivalent to a simultaneous rotation about OA and AA' where directions and magnitudes are completely represented by these axes. The rotation AA' is of course directly opposite to the rotation expressed by $A'A$.

Now destroying the rotation AA' is equivalent to superposing upon the rotation OA' a contrary rotation $A'A$ so that in every half period the Moon will have effectually added this contrary rotation from A' to A, while in the other half she will have as effectually added a rotation in the opposite direction A to A'. In this latter half period the added direct rotation will at all times be balanced in its gyroscopic effect by the added attractional couple, but in the first half the superposed contrary rotation $A'A$ will not be balanced by an attractional component. The result is that this rotation will produce gyroscopically a rotation of the Earth about an axis through O perpendicular to the page and in a direction such as to decrease the declination. This residual contrary rotation though exerted only during half the period is cumulative and the result will be to give the Earth a rotation with gradually increasing acceleration. We might liken this action of the Moon due to the shifting inclination of her orbit, to a pawl and ratchet. It is as if she moved up to her minimum position to get a good leverage and then pulled down to her maximum position, moving back again to her minimum position again without exerting any effect. Of course actually this is not the case: it is merely a simile. As a matter of fact the pull is exerted in the passage from the maximum to the minimum position.

The reader will see the principle involved here clearly from the following consideration.

If Ω_1 be the maximum rotation about the axis OL, it will be necessary to superpose upon this rotation a gradually increasing rotation $-d\Omega$ in the opposite direction, so as to bring the resultant down to the minimum rotation Ω_2.

This rotation, which is unbalanced by any other force will evidently cause the axis of the Earth to move towards coincidence with the line *OL*, with an increasing acceleration. On the other hand, in increasing the rotation again from Ω_2 to Ω_1, all the forces called into play will be exactly balanced. The pole of the Earth, therefore, will move towards the pole of the ecliptic, not steadily, but with periodical accelerations. On the average, however, this velocity will be a continually increasing one. On a somewhat analogous principle, a top spinning on a rough surface gradually spirals inwards to a position of perpendicularity. This is due to friction on the surface of the peg which causes it to roll slightly with a corresponding increase in the precessional angular velocity. The result is that the top gradually rights itself at the expense of its original rotational energy. Those who have watched a top start with a certain inclination will recall the manner in which it winds itself upwards to an erect position; the boys say that it is now "asleep". As the rotation decreases, it falls off a little and the peg surface now begins to roll in spirals which continually increase outwards until the top comes in contact with the ground.

We have said that the semi-annual and the semi-monthly perturbations of the Sun and Moon are unimportant, and so they are in themselves. It is, however, through their agency that the residual component of the maximum rotation is destroyed so as to leave only the minimum rotation as the surviving part of the maximum rotation. Let us suppose that the Moon having completed one semi-monthly perturbation, the plane of her orbit is slightly shifted for the ensuing semi-periodical perturbation. The amount of each elementary rotation and the direction in which it takes place is also correspondingly changed, so that the average of their sum is fitted for the new position.

This means that the amount of the rotational energy about the precessional axis may be diminished or increased as well as that the direction of this axis is changed. When the energy is diminished, this means that a certain rotational component is destroyed. This means of course that it is destroyed in so far as it is balanced against any attractional couple. It actually reappears as an acceleration increasing the inclination of the Earth's axis.

If then we start the Earth with a certain inclination to the ecliptic and then leave it to the gravitational actions of the Sun and Moon, we have seen that the first effect is to produce a constant precessional motion of the pole about the pole of the

ecliptic. The pole will not trace out a smooth circle but this circle will be rendered slightly wavy by reason of minute semi-annual and semi-monthly perturbations due to the Sun and Moon.

By reason of the perturbations set up by the Moon's shifting her orbit about the pole of the ecliptic there will be a further disturbance of the pole having a nineteen year period.

But this is not all. Coincidently with this nineteen year perturbation there will be a very small but constant raising of the Earth's axis, so that its inclination to the ecliptic becomes continually greater. This motion will be slow at first, but continually accelerated, until eventually the Earth's axis is brought to a condition of perpendicularity to the ecliptic.

In this position all precessional forces cease, but the momentum acquired by the Earth's straightening up its axis carries it beyond and it will finally reach an inclination in the other direction equal to the inclination from which it started. While the inclination is decreasing, or the inclination of the equatorial plane to the ecliptic is increasing, the residual rotation of which we have spoken above is continually opposing it until finally the inclination is brought to its original amount. The axis therefore swings backwards and forwards like a pendulum from some original inclination, through a position of perpendicularity, to its original inclination again. This is repeated over and over again with a very slow motion and with a very long period.

The pole does not therefore trace a closed circle about the pole of the ecliptic, but at every revolution finds itself a little nearer or a little farther, as the case may be, from this pole. In other words the curve is not re-entrant, but a spiral. It circles in towards the pole in a spiral, passes through this point and then spirals out again to its original position. The motion is most rapid at the pole of the ecliptic and becomes zero at either extreme position, precisely as in a pendulum.

There is one critical position for such a motion, viz., when the attracted body starts with an inclination of 45° to the ecliptic. With the Sun and Moon as attracting bodies, a precessional rotation with an unvarying inclination would be the result, and the rapidity of this motion would be a maximum. The Moon's nineteen year shift of her orbit would produce no residual rotation in this position. Consequently a body starting with this inclination would maintain it forever afterwards. But if from some planetary disturbance it should be displaced by the slightest amount on one side or the other from this position, two cases would result. If it fell over so as to increase the inclination of

the pole, the axis would fall through a position of perpendicularity and then tip over up to 45° on the other side; but it would not go beyond 45°. It would thus oscillate between limits of 45° through the condition of perpendicularity.

But if it fell to the other side, it would continue until the plane of the equator was perpendicular to the ecliptic after which it would continue until it was inclined by an angle of 45° on the other side.

The Earth is at present decreasing its equatorial inclination to the ecliptic by about 47″ in a century. Our inclination at present is a little more than 23° 27′. At the beginning of the Christian era it was about 24°. It must be remembered that the ecliptic itself is not fixed in space, but slowly varies its position between limits less than 3°.

It is therefore certain that the Earth's equator can never have been inclined at a greater angle than 45° to the plane of the ecliptic, but it is possible that it has been inclined as much. On the other hand the planet Uranus has at present its equator inclined probably somewhere about 90° to the ecliptic. It can never have been less than 45°, but may have been this amount at some time.

At present our data are hardly sufficient to determine the time it takes the Earth's axis to make its long swing through the position of perpendicularity nor to determine the maximum position. We know that this inclination of the axis is increasing by something like 47″ in a century, but it is not constant from century to century. The rate seems to be increasing for each century, so that we are justified in concluding that the Earth is now passing from a position of extreme inclination of its equator to one of coincidence. We do not yet know what the extreme inclination of the equator was, but it could never have been greater than 45°.

Let us suppose that it started from an inclination of 35°. At such a time the arctic circle would come down to 55° of latitude. All the regions above this latitude would be subjected to a long arctic night of six months. Provided there was abundant precipitation, all this region would be covered with masses of ice which the six months' summer could not melt. Not only would all the region north and south of 55° be glacialed, but the ice masses would extend to a considerable distance below this latitude. We find undoubted evidences of all this having taken place in the comparatively recent past. Of course the equatorial border of these ice masses would not be limited by a parallel of

altitude, but would vary according to local conditions chief of which would be the local precipitation and the elevation. We find evidence that these ice sheets extended as far south as 50° of latitude in Europe and in some places in North America, as far as 38° of latitude. There is evidence that these ice sheets moved over the surface of the Earth in a generally equatorial direction, which can be accounted for by a gravitational slope in this direction. The effect of centrifugal force due to the Earth's rotation would be to create a slight slope in this direction.

The writer wishes it to be understood that this paper was not written to exploit a new glacial theory. There have already been formulated many hypotheses to explain the various glacial epochs through which the Earth has passed, many of them impossible and all of them inadequate. We shall not mention them as the purpose of this paper is dynamical and not geological. We are here simply considering the various forces at work in gyroscopic motion and have been led to examine a resulting change in the inclination of the Earth's axis due to these forces. This has been merely an incident of our general examination, and no direct purpose connects it with any explanation of glacial periods. In other words if these glacial epochs have been explained, it has been merely incidental.

When the Earth's axis stands perpendicular to the ecliptic, there can be no ice at the poles and a tropical vegetation can exist far to the north. Of this also, we have plenty of evidence, the remains of tropical species being found not far from the poles. Plants and animals similar to those now found in the tropics once flourished in Greenland which is now glaciated. There is evidence that this glaciation is now decreasing so that in time a solubrious climate will once more be restored to Greenland.

Again after passing through an approaching genial period the Earth must once more become ice-bound and so on through unceasing cycles. The speculation thrusts itself upon us whether the abrupt extinctions of various animal forms in the past were not due to these changing cycles. Thus the age of reptiles came to an abrupt close after existing for many years.

It seems plausible to suppose that they were practically totally destroyed by an oncoming glacial period and the succeeding period knew them no more. In their places grew an entirely new creation, descendants of the survivors of the previous period. Certain it is that the geological history of the Earth is written in separate complete volumes, and the partitions between these volumes are as definite as the covers of a book. But, as we have

said before, our purpose in this paper is not speculation and hypothesis, but a mathematical examination of gyroscopic motion. We began with a top and following through the principles which govern this simple toy, found that we could trace the path of a storm. Leaving the Earth we found that we could foresee the precession of the equinoxes with its various accompanying perturbations and nutations. Coming back to the Earth again we found we could predict cycles of vast change in the climate of the Earth as a whole, having the most profound and far-reaching consequences. And all this because of the principles governing gyroscopic motion. Surely the study of a science which enables us to draw such remarkable conclusions and to learn so much of the universe in which we live deserves to find a place in the educational scheme of every man.

Worcester, Mass.

MISS AGNES MARY CLERKE

HECTOR MACPHERSON JR.

FOR POPULAR ASTRONOMY.

The news of the death of Miss Agnes Clerke, which took place at her London residence on January 20, came on the scientific world with a shock of surprise. Miss Clerke, through her exhaustive and accurate works on astronomy, had gained the respect and esteem of astronomers throughout the world, and the same is distinctly poorer by her loss.

Born in County Cork, Ireland, in 1842, Agnes Mary Clerke commenced the study of astronomy at the early age of eleven. At that age, as she remarked recently in a letter to the writer, she mastered Sir John Herschel's "Outlines of Astronomy", and for many years she kept up an interest in the science, although unknown in the astronomical world. From 1870 till 1877—when she settled in London—Miss Clerke resided in Italy. Her first astronomical work was an article, published in 1879 in the "*Edinburgh Review*" on the chemistry of the stars. Two years later, she commenced her exhaustive and epoch-making work "A Popular History of Astronomy during the Nineteenth Century", a work for which she received the universal applause of astronomers. Miss Clerke was occupied with this book for four years, and it was not until late in 1885 that it was published. It supplied a distinct want, and was widely appreciated, entering into new editions in 1887, 1893, and 1902 respectively. After the

work was published, Miss Clerke devoted herself to practical astronomical work, the examination of celestial photographs, from which she deduced that the Universe is not infinite in extent. In 1888 Sir David Gill, then director of the Cape Observatory, invited Miss Clerke to pay him a visit, at the same time placing a telescope and spectroscope at her disposal. Thus equipped, she commenced an examination of the southern skies, devoting herself specially to the colors of stars, and to the survey of individual stellar spectra. On her return to London, she commenced

Miss Agnes Mary Clerke.
(1842-1907)

another important work, which was published in 1890 and entered a second edition in 1905—namely "The System of Stars". In this work, Miss Clerke gave a most exhaustive and scholarly survey of the investigations, discoveries, and unsolved problems in the realm of sidereal astronomy.

In 1895 Miss Clerke published another important work, "The Herschels and Modern Astronomy," biographies of William, Caroline, and John Herschel. This was followed in 1898 by "The Concise Knowledge Astronomy," which Miss Clerke wrote in conjunction with Mr J. E. Gore and Mr. A. Fowler. In 1903,

she published her "Problems in Astrophysics", a survey of the state of our knowledge of both solar and stellar spectroscopy. On the publication of this work, she was, along with Lady Huggins, admitted an honorary member of the Royal Astronomical Society. According to the constitution of the Society, men alone can be elected as fellows, and the only previous lady members were Caroline Herschel and Mary Somerville. In 1906 Miss Clerke published her last work, "Modern Cosmogonies," in which she more than sustained her high reputation as an astronomical writer.

Miss Clerke's most important work was undoubtedly her "History". The place which it holds in astronomy is both unique and authoritative. The outcome of much laborious study, she did not allow her book to fall behind the times. The new editions were in a certain sense new volumes. The result is that the work holds the same high position to-day that it did after its first publication, and it is much to be hoped that it will not be allowed to fall out of date, but that some astronomer may succeed in keeping it in line with the discoveries of the times. Miss Clerke's other works were careful discussions of our present knowledge. For both stellar astronomy in general and the department of the science known as astrophysics, Miss Clerke did excellent work, and it is to be regretted that she did not publish a work dealing in the same authoritative way with planetary and lunar astronomy.

So careful were her discussions and so unbiased her judgments that astronomers all over the world looked up to her as a high authority. A British weekly paper remarked at the time of her death "At meetings of the Royal Astronomical Society, she was frequently to be seen surrounded by leading astronomers, genuinely keen to hear her opinion on some knotty point." In her works, she was not content with merely chronicling the progress of discovery. Her books have a wide outlook on the Universe as a whole. She goes beneath the surface of things and writes in a spirit of religious humility. As an example of her style we may take her discussion of the ultimate fate of the Universe—"The glory of the heavenly bodies, it is asserted, must come to an end. It results from a merely transitory state of things. The radiations, by virtue of which they shine, are the outcome of what may be figuratively termed the effort of nature to establish a universal thermal equilibrium. This condition will be attained when the frigid temperature of space reigns in all the millions of bodies which once were suns, and will thenceforth

revolve amid 'darkness that may be felt'—the mechanism of their movements unimpaired, but inert, lifeless and invisible. Is this, then, the predestined end? Science replies in the affirmative. That is to say, it knows no better. That is all we know; at the brink of the ocean we pause, helpless to sound its depths, or number the modes of its manifestations, or predict the tasks of renovation or preservation committed to it. We can only recognize with supreme conviction that He who made the heavens can restore them, and that when the former things have passed away and the scroll of the skies is taken out of sight, 'like a book folded up,' a 'new heaven and a new Earth' shall meet the purified gaze of recreated man."

It is this blend of scientific accuracy and reverent thought which gave Miss Clerke's books their deservedly high place in the astronomical world.

Johnsburn,
Midlothian, Scotland.

APRIL METEORS.

W. F. DENNING

For Popular Astronomy.

April, even with its Lyrids, forms a month when meteors are somewhat rare. The Lyrids are presented richly on one night only (April 21, since 1900) and the other dates usually supply not more than four or five meteors per hour for one observer.

In respect to weather the period is often formidable. In England we may have to watch either in a winterly or summerlike atmosphere but be the temperature high or low the sky is often clear and so this spring shower is more often witnessed than the Quadrantids or Boötids of January which are frequently hidden in clouds.

The scarcity of meteors in the vernal season is often apt to try the patience of the observer. There are however a great many minor showers in play and to the persevering student very interesting results are promised concerning these. For the special period marked by the return of the Lyrids our knowledge is fairly complete a large accumulation of materials having been discussed and the radiants of nearly all the contemporary showers

carefully ascertained. But for other periods and especially for April 1-5, 10-12 and 28-30 our information is meagre and more attention is necessary for these. In 1879 I derived the radiants of twenty-one showers from a considerable number of foreign observations and the results were published in *Monthly Notices* R.A.S. XXXIX p 404 but an individual observer would probably get the radiants much more accurately from his own observations (could he secure ample data for the purpose) than can be effected from many combined results some of which must be unreliable.

The following are a number of the principal centers of radiation found for secondary showers visible at the period of the Lyrids:

α	δ	α	δ
189	− 31	234	+ 10
202	+ 9	239	+ 46
203	− 10	210	+ 62
213	+ 53	262	+ 36
217	− 35	272	+ 21
218	− 5	300	+ 22
219	+ 36	315	+ 78
231	+ 17	316	+ 48

Many other systems will become evident after close and long continued watching. But it is difficult to select what are really the most active displays for though the majority of meteoric streams appear to be annually visible they exhibit considerable variation in strength from year to year.

Those who observe the Lyrids in this, or indeed in any year will do well to ascertain the exact time and strength of the shower at maximum. Another important feature lies in the apparent displacement of the radiant point which is at 271° + 33° on April twenty-first and moves $1^1/_4$° of R.A. daily to the eastward during its visibility from about April 17 to 25. But the display is generally very feeble indeed except on the night of maximum and a single observer will find it difficult to trace the motion of the radiant until he has accumulated observations during several years. An ephemeris based on Lyrid paths recorded at Bristol during thirty-four years (1873-1906) gives the following mean positions:

	α	δ		α	δ
April 16	264¾	+ 33	April 21	271	+ 33
17	266	+ 33	22	272½	+ 33
18	267¼	+ 33	23	273½	+ 33
19	268½	+ 33	24	274¾	+ 33
20	269¾	+ 33	25	276	+ 33

Bristol, England.
1907 January 9.

TELESCOPIC METEORS.

W. F. DENNING.

For Popular Astronomy.

With reference to the interesting remarks of Mr. Joel H. Metcalf (*Popular Astronomy*, January 1907) a good deal of information can be found in various astronomical publications of past years about telescopic meteors.

Schmidt saw 146 of these objects of the seventh to eleventh magnitude during ten years. Winnecke in 1854 noticed 105 on thirty-two evenings of observations with a three-inch finder, power fifteen, field 3°. Safarik observed hundreds of meteors of every magnitude from the second to the twelfth pass through the field of his six and one-half-inch reflector (ordinary power thirty-two, field 54′). On August 30, 1880 ninth to fifteenth he counted between 50 and 100 telescopic meteors and many others were seen on the following night (*Ast. Register* XXIII p. 205).

During the years from 1881 to 1900 the writer at Bristol during 715 hours spent in comet seeking observed about 660 telescopic meteors. The instrument used was a ten-inch reflector with a power of 40 and field of 65′.

Others have published some details of the same kind but I am afraid that many observers during their work on variable stars or in comet seeking have not preserved particulars of their nightly experiences.

I have several times called attention in the *Monthly Notices R. A. S.* and *Observatory* to the importance of paying more attention to telescopic meteors. Those observers engaged in the special lines of work which enable them to see numbers of these bodies would do well to record the detail of their numbers and appearances. To attempt to register the individual paths would occupy much valuable time but the observer might note the dates and duration of observation, telescopic power and diameter of field employed, number of meteors seen etc.

I found the rate of apparition rather less than one per hour, and what often struck me as suggestive was the apparent slowness of motion of the meteors as they traversed their short paths, often less than 1°. I inferred from this and from their faintness that they were probably far more distant than the ordinary naked-eye meteors.

With regard to the so-called showers of telescopic meteors

sometimes seen near the Sun these may be dismissed as of purely terrestrial origin and composed of seeds, snow or other particles floating high in the air and carried along a wind current. I have witnessed many of these telescopic showers but they represented something very different from meteoric objects.

Bristol, England.
January 6, 1907.

PHOTOGRAPHS OF FAINT STARS.

EDWARD C. PICKERING.

The number of facts now being accumulated by means of photographs of the stars is enormous. Unfortunately only a small portion of these facts is now available, and therefore of any use to science. This applies particularly to the faint stars. Many photographs are taken by professional and amateur astronomers, which are followed carefully during long exposures with telescopes having large apertures. In some cases, several hundred thousand stars appear upon a single plate. Unfortunately, no record has been published of many of these photographs, and therefore no use can be made of them. It is the object of the plan described below to remedy this difficulty.

The Harvard collection of photographs in part supplies this need, for stars of the thirteenth magnitude and brighter. On the average, this collection contains of all the stars of the fifth magnitude and brighter on over a thousand nights. The number of these stars is about two thousand, the photographs are distributed throughout the last twenty years, and cover all parts of the sky. For stars of twelfth magnitude, which can be taken with a lens of 1-inch aperture and an exposure of one hour, the number is reduced to five hundred. This includes the stars in the Harvard map of the sky, about two million in number. There are about five million stars of the thirteenth magnitude and brighter. They appear on plates taken with 8-inch doublets, and having exposures of ten minutes. About two hundred images of each of these are contained in the Harvard collection. For fainter stars, the number of images falls off very rapidly. Stars of the fourteenth magnitude would appear on plates, having exposures of ten minutes, taken with the 24-inch Bruce telescope, and on plates, having exposures of an hour, taken with the 8-inch telescopes. The average number of times the whole sky is thus covered does not exceed three or four. A large part

of the southern sky is covered by plates having an exposure of an hour or more, taken with the 24-inch Bruce telescope. One hundred and sixty regions covering a tenth of the sky, have exposures of four hours. While, therefore, material exists for studying the variability of the thirteenth magnitude or brighter, but few images can be found of stars much fainter than this limit, except in special cases like the Nebula of Orion. This limit could probably be extendednearly two magnitudes, if the following plan could be carried out. For the present it seems best to confine this work to photographs having an exposure of half an hour or more, and taken with doublets whose aperture is six inches or more. Photographs taken with large reflectors or single lenses may take fainter stars, but in general they relate to special regions and except in the charts of the Astrographic Congress do not cover large parts of the sky. The latter great work will of course, eventually, furnish one or two images of all stars of the fourteenth magnitude, and brighter.

Information is frequently desired regarding very faint stars. For instance, evidence of the previous existence of a new star; of a star now missing; the position of an asteroid; the magnitude at minimum of a faint variable; early position of a faint star suspected of proper motion. Three questions suggest themselves. Where are the principal collections of photographs showing faint stars, and what is their character and extent? Does a photograph exist which is likely to contain the required information? Is this photograph accessible, so that the information desired can be secured from it? Satisfactory answers to these questions can generally be obtained for stars brighter than the thirteenth magnitude but not for fainter stars. Astronomers having collections of photographs showing such faint stars are urged to publish the material required to answer these questions, or to send the information needed to this Observatory. The principal facts desired are given below:—

1. A description of the instrument, stating its location; form of lens; maker; aperture; focal length, or scale of photograph, that is, number of seconds of arc to the millimetre; size of plate, or region covered; diameter of circle over which stars as faint as the fourteenth magnitude are shown; kind of plate used; name of observer.

2. A list of photographs, which should include the number designing each plate; the time of the center of the exposure (found by adding half the duration of the exposure to the time of beginning), expressed either in Julian Days and thousandths

following Greenwich Mean Noon, or in calendar days, hours, and minutes; the right ascension and declination for 1900 of the center of the plate; the time of exposure in minutes; the quality on a scale of 5, 5 denoting that the images are circular and that no serious defect appears upon the plate, 4 that the images are nearly circular so that their positions can be accurately measured, 3 that faint stars are shown so that the relative brightness can be accurately estimated, even if the images are not circular.

3. A statement whether the owner is willing to examine and if necessary measure his photographs to furnish any desired information; to lend them under suitable restrictions, so that copies may be made; to furnish contact prints at cost.

It is the policy of the Harvard Observatory to make the material it has collected as widely useful as possible. Accordingly, preparations are being made to publish the facts asked for in Nos. 1 and 2. For many years the Observatory has offered to furnish copies of its photographs at cost to whoever might desire them. If this policy is adopted at other observatories, a purchase of large numbers of photographs of faint stars is contemplated here. The Observatory will take charge, temporarily or permanently, of good photographs for which the owners have no further use, and will render them accessible to astronomers by the methods described above.

Harvard College Observatory.
Circular 123.

PROBLEMS OF SOLAR PHYSICS.*

A. L. CORTIE.

To the zeal and energy of Professor George E. Hale is due the inception of an international union for the study of Solar Physics, which should include among its members both astronomers and physicists representative of the leading scientific academies of the world. The first meeting of the delegates, sixteen in number, from fourteen different academies of the mixed nationalities, took place at St. Louis on September 23, 1904; the second, at which forty members were present twenty-three of whom were delegates from eight different nations, assembled at New College, Oxford, on September 27-29, 1905. The Transactions of these two meetings, with papers either read at the conferences or pre-

* The *Observatory*, February, 1907.

pared in view of the conferences, together with the resolutions adopted and the rules for the constitution of the Union, have been gathered together in a valuable and handsome volume under the care of Professor Schuster, of the University of Manchester, which appears with the title of Vol. I. of the Transactions of the International Union for Coöperation in Solar Research*. There are four main problems, or lines of research, which engaged the attention of the delegates present at the meetings, and which formed the subject matter of the resolutions which were eventually adopted after ample discussion. These problems concern the determination of reliable standards of wave-length, the exact measurement of the intensity of solar radiation, the study of the spectra of sun-spots, and the study of the records, by means of the H and K light, of the phenomena of the solar atmosphere, while a related problem, namely that of the solar rotation as measured by spectroscopic methods, came up for review, without, however, leading to the formulating of any definite resolutions. The progress of physical science is indissolubly bound up with exactness in quantitative measurement; very fittingly therefore was the attention of the Union directed at the very outset to the subject of the value of the fundamental wave-lengths which constitute the basis of all exact observation in spectroscopy. It would at first sight have appeared that the immense labors of Rowland of Baltimore, which resulted in the construction of gratings of great purity, and a photographic map and tables of the solar spectrum giving the positions and intensities of some 20,000 lines, besides identifications with the arc-spectra of most of the known elements, would have sufficed for the needs of even the most exact spectroscopy for generations to come. But in an age when it is possible to measure radial velocities of stars to the hundredth of an Ångström unit, which corresponds to a line of sight velocity of 0.7 kilometers per second, tables of standard wave-lengths are required at least to this degree of accuracy; and although Rowland's Tables purport to be exact to three places of decimals, yet they have been found wanting in parts even to two. An interesting paper by Mr. Jewell gave the history of the construction of Rowland's map and tables. The fundamental wave-length upon which they depend is that of the D_1 line as determined by Bell, and the wave-lengths of the other lines were derived by the method of coincidence between the lines in different orders of the spectrum. But

* Manchester: at the University Press, 1906. Pp. xii and 257. Published by Messrs. Shenatt & Hughes. Price 7s. 6d. net.

the fixing of the wave-length of the red cadmium line in terms of the standard metre by Michelsen by means of the interferometer, a result which has been independently confirmed with an instrument of somewhat different construction by Fabry and Pérot, virtually implies errors in the standard position of the lines measured with reference to D_1. The fault seems to lie in the gratings themselves, which have proved to be not sufficiently accurate instruments for the determination of absolute wave-lengths. Mr. Jewell contended for the re-measurement of Rowland's best series of plates, and the re-determination of relative wave-lengths from them, and naturally deprecated haste in setting aside Rowland's gigantic work. Hartman also would patch up Rowland's Tables. The conference at Oxford determined, however, that a suitable spectroscopic line shall be taken as the primary standard of wave-length, which shall be fixed permanently and thereby define all other wave-lengths and their unit. This unit, which is to be called the Ångström, shall differ as little as possible from 10^{-10} metres. Secondary standards are to be at distances apart of 50 Ångströms, also determined by interferometer methods, while tertiary standards at distances of five to ten Angströms are to be interpolated by the use of gratings.

The subject of the solar emission of energy and the exact determination of the "solar-constant" was treated of in papers by several physicists, and in particular in a lengthy and most valuable review of the whole subject by Professor Abbot. One interesting point touched upon was the actual variability of the solar radiation in itself, independently of that due to meteorological conditions. And here it is well to mention that the solar physicists join hands with the meteorologists, and that the solar Commission of the International Meteorological Committee was represented among the associated academies. But to return to the intrinsic variability of the solar radiation itself. It was suggested by Professor Julius that this was due to unequal distribution in various directions, which was conditioned by inequalities in the Sun's field of radiation. This would result from ray-curving in the strata and vortices of the solar gases, the order of magnitude depending on the refractive indices of the various gases. Although experiments with all forms of apparatus for registering the intensity of solar radiation were encouraged, especially ingenious pieces of mechanism being described by Professor Abbot and Professor Callendar, the standard instrument adopted by the Union was the electrically controlled compensating pyrheliometer of Professor K. Angström. The Union, more-

over, resolved that for the determination of possible changes in the solar-radiation power, measurements of radiative intensity should be secured over limited ranges of the spectrum which are not affected by absorption due to constituents of the atmosphere such as ozone, water-vapor, and carbonic acid.

In his presidential address to the first Conference at St. Louis, Professor Hale insisted upon the necessity of a fuller knowledge of the spectra of sun-spots. One of the committees of the Union has charge of the observations in this important branch of solar physics, and of this committee Professor Alfred Fowler is the active secretary.

In the present volume appears a noteworthy paper by Professor Fowler, with a table and a map, which is to serve as a model for the presentation of their results by other observers. The observations were made during fifteen months in the years 1905-6, and cover the part of the spectrum included between the lines b_4 and E_1. Treating of the bands which are to be found scattered over the general darkening of the continuous spectrum due to the spots, Professor Fowler calls attention to the structure of these bands, which resemble the fluted spectrum of chemical compounds, and the bright gaps of separation in the general darkening which are generally found to extend over the photosphere and are bounded on each side by lines to the ordinary Fraunhofer spectrum which have a faint and hazy appearance. The inference is that the material which gives rise to the spectrum of bands in the general darkening due to a spot, while concentrated in the spots, is scattered thinly over the entire photosphere. The origin of this spectrum has so far eluded detection. Coming now to the lines which are affected in the spots, Professor Fowler finds in the first place that the selective widening does not differ from spot to spot, but is constant. This position, at least as far as regards the red end of the spectrum, has been substantially insisted upon in several papers by the present writer during the last twenty years*. An important point dealt with by Professor Fowler is that of the lines which are weakened or obliterated in sun-spots. These are found to be high-level chromosphere lines, and moreover are precisely those lines which are enhanced in passing from the arc to the spark. When there is added to this fact the further facts appearing in the discussion, that for chromium and iron the relative order of intensification in spots corresponds to that of the arc or solar spectrum, and further that in the case of iron and vanadium, this element being one of the chief con-

* *E. g.* M. N. R. A. S. vol. xlix. no. 8, p. 417, June 1889.

PLATE IV.

CITY OBSERVATORY, CALTON HILL,

[Founded 1776]

EDINBURGH.

stituents of sun-spots, the lines especially intensified are those characteristic of the arc-flame spectrum, the conclusion that the additional selective absorption in sun-spots is produced by relatively cool vapors seems to be a legitimate one. In a word, the darkness of a spot is due to absorption caused by a lowering of temperature. This view corresponds with that of Professor Hale and his coadjutors, as was so admirably set forth in the January number of the *Observatory* by the late lamented Miss Agnes Clerke. Although in point of time of actual publication the American results were first in the field, we happen to know that Professor Fowler's paper has been awaiting publication for a considerable period. That two lines of research upon the spectra of sun-spots independently undertaken, the one visual and the other photographic, should have led to the same general conclusion is worthy of note. At the same time it is only fair to state that such authorities as Mr. Evershed and Mr. Maunder hold that the darkening of a sun-spot is due to diminution of radiation. The spots are, on this view, really hotter than the photosphere, the photospheric clouds having been evaporated by a local access of heat. It is difficult, however, to reconcile this view with the existence of spot-bands, which, as pointed out by Professor Young and the present writer long ago, are indicative of such a lowering of temperature over the regions of sun-spots to allow of the formation of chemical compounds.

HECTOR MACPHERSON, Jr.

Our readers have been interested from time to time in some briet articles furnished for our paper by Hector Macpherson Jr., of Scotland. It may not be known to many that he is a young man now only eighteen years old. He is the son of a Scottish journalist whose home is in Johnsburn, Bolerno, a few miles from Edinburgh. In the *Chicago Tribune* of February 3, 1907 other facts are found. It is said that at the age of twelve his father decided that his son was a "born astronomer," his choices in that direction were so strong and the work he was then able to do was really so notable for one of his years. He became interested in the astronomy to be found in the French, German and Italian languages, and as he had no means of getting the translations wanted, he rapidly acquired knowledge of these languages so that he could do the translating for himself. He has already published two books, one on "Astronomers of Today" and the other on "A Century's Progress in Astronomy." Young Macpherson is a member of the Societe Astronomique de France and a member of the Societé Belge d'Astronomie.

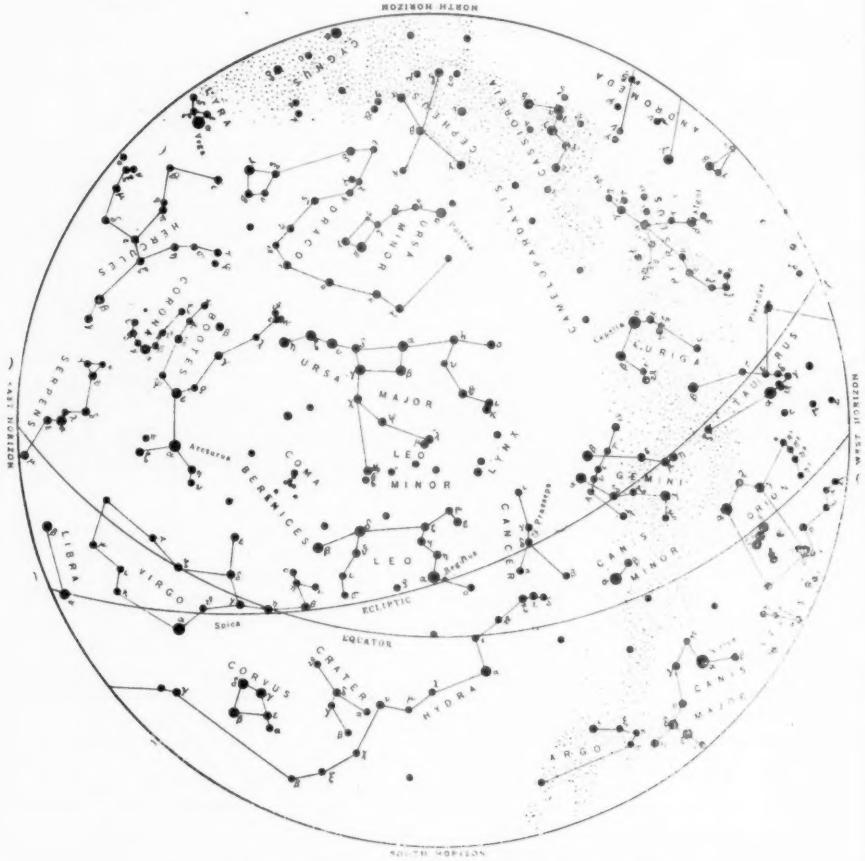
We had intended to present last month, in connection with Mr. Macpherson's article on the Observatories of Scotland the accompanying view of the Edinburgh Observatory, on Calton Hill, but the photograph was lost in transit and a duplicate could be procured only in time for this number. [THE EDITOR.]

PLANET NOTES FOR APRIL, 1907.

H. C. WILSON.

Mercury will be at greatest elongation, west from the Sun 27° 36′, April 14, but being on the slope of the ecliptic southward from the Sun will not be easily visible to northern observers. Mercury will be in conjunction with Saturn April 8, at 11^h, C. S. T., the two planets being then only a half degree apart in declination.

Venus is morning star in Aquarius, rising in the southeast about two hours before the Sun. Her brilliancy will decrease from 88 to 70 during the month. Venus and Saturn will be in conjunction on the morning of April 21, Venus being then 38′ north of Saturn.



THE CONSTELLATIONS AT 9:00 P. M. APRIL 1, 1907.

Mars is in Sagittarius this month, moving eastward, and will come into conjunction with Uranus on the first day of May. The apparent diameter of Mars will be 10″ on April 1 and 13″ at the end of the month so that work may be begun on the study of the surface markings during the coming opposition. The low altitude of the planet will, however, prevent northern observers from doing very much in this line during the spring and summer.

Jupiter is still in good position for early evening study but will soon be too low in the west.

Saturn on the farther side of the Sun is in unfavorable position. Its conjunctions with Mercury April 8 and with Venus April 21 have already been referred to.

Uranus is in Sagittarius, very low in altitude for northern observers. It will be at quadrature, 90° west from the Sun on the morning of April 3.

Neptune is visible with the aid of a telescope, in the early evening. It is in Gemini a little way east of Jupiter.

Occultations visible at Washington.

Date 1907	Star's Name	Magnitude.	IMMERSION. Washington M.T. h	m	Angle from N. °	EMERSION. Washington M.T. h	m	Angle from N °	Duration h	m
April 1	η Libræ	5.5	10	21	118	11	23	289	1	02
1	δ Libræ	4.4	16	03	127	17	18	271	1	15
4	30 Libræ	6.2	13	34	130	14	30	246	0	56
6	20 Capricorni	6.2	18	03	85	19	25	248	1	22
17	χ^1 Orionis	4.5	11	03	106	11	55	256	0	52
22	34 Leonis	6.4	13	23	72	14	08	330	0	45
23	*l* Leonis	5.3	5	18	159	6	09	242	0	51
26	80 Virginis	5.6	13	21	107	14	32	307	1	11
29	χ Ophiuchi	4.9	12	49	69	13	47	331	0	58

Phenomena of the Satellites of Jupiter.

1907 Central Standard Time, reckoning from noon.

April	1	7h 01m	II Sh. Eg.	April	15	6h 54m	II Tr. In.
		8 10	IV Ec. Re.			7 28	I Sh. Eg.
	3	8 12	III Sh. Eg.			9 24	II Sh. In.
	5	10 18	I Oc. Dis.			9 46	II Tr. Eg.
	6	7 30	I Tr. In.		17	6 34	II Ec. Re.
		8 46	I Sh. In.			8 04	III Tr. In.
		9 20	II Oc. Dis.		21	8 44	I Oc. Dis.
		9 47	I Tr. Eg.		22	7 05	I Sh. In.
		11 04	I Sh. Eg.			8 12	I Tr. Eg.
	7	8 19	I Ec. Re.			9 23	I Sh. Eg.
	8	6 46	II Sh. In.			9 38	II Tr. In.
		7 03	II Tr. Eg.		23	6 40	I Ec. Re.
		9 39	II Sh. Eg.		24	9 09	II Ec. Re.
	10	7 01	III Tr. Eg.		26	8 30	IV Sh. In.
		5 55	III Sh. In.		28	6 54	III Ec. Dis.
	13	9 27	I Tr. In.			10 04	III Ec. Re.
		10 41	I Sh. In.		29	7 53	I Tr. In.
	14	6 45	I Oc. Dis.			9 00	I Sh. In.
		10 15	I Ec. Re.		30	8 35	I Ec. Re.
	15	6 14	I Tr. Eg.				

Note.—In., denotes ingress; Eg., egress; Dis., disappearance; Ec., eclipse; Oc., occultation; Tr., transit of the satellite; Sh., transit of the shadow.

VARIABLE STARS.

Minima of Variable Stars of the Algol Type.

[Given to the nearest hour in Greenwich Mean Time beginning with noon. To reduce to Central Standard time subtract 6 hours, or for Eastern time subtract 5 hours.]

U Cephei

	d	h
Apr.	1	9
	3	21
	6	9
	8	21
	11	9
	13	20
	16	8
	18	20
	21	8
	23	20
	26	8
	28	19

RX Cephei

Apr.	6	18

λ Tauri

Apr.	2	11
	6	10
	10	9
	14	8
	18	6
	22	5
	26	4
	30	3

RW Tauri

Apr.	5	22
	8	16
	11	11
	14	5
	16	23
	19	18
	22	12
	25	7
	28	1
	30	20

RW Persei

Apr.	2	15
	15	20
	29	0

RS Cephei

Apr.	9	13
	21	24

RW Geminorum

Apr.	3	9
	6	6
	9	3
	11	24
	14	21
	17	17
	20	14
	23	11
	26	8
	29	4

R Canis Maj.

	d	h
Apr.	1	11
	2	14
	3	18
	4	21
	6	0
	7	3
	8	7
	9	10
	10	13
	11	16
	12	20
	13	23
	15	2
	16	6
	17	9
	18	12
	19	15
	20	19
	21	22
	22	1
	24	4
	25	7
	26	11
	27	14
	28	17
	29	21
	30	24

Y Camelopardis

Apr.	2	9
	5	16
	8	24
	12	7
	15	14
	18	22
	22	5
	25	12
	28	20

RR Puppis

Apr.	4	22
	11	9
	17	19
	24	5
	30	16

V Puppis

Apr.	2	9
	3	20
	5	6
	6	17
	8	4
	9	15
	11	2
	12	13
	13	24

V Puppis

	d	h
Apr.	15	11
	16	22
	18	9
	19	19
	21	6
	22	17
	24	4
	25	15
	27	2
	28	12
	29	24

X Carinæ

Apr.	1	2
	2	4
	3	6
	4	8
	5	9
	6	12
	7	14
	8	16
	9	18
	10	20
	11	22
	12	24
	14	2
	15	4
	16	6
	17	8
	18	10
	19	12
	20	14
	21	16
	22	18
	23	19
	24	21
	25	23
	27	1
	28	3
	29	5
	30	7

S Cancri

Apr.	8	12
	18	0
	27	12

S Velorum

Apr.	1	13
	7	11
	13	10
	19	8
	25	6

RR Velorum

	d	h
Apr.	1	17
	3	14
	5	10
	7	7
	9	3
	10	24
	12	20
	14	17
	16	13
	18	10
	20	6
	22	3
	23	23
	25	20
	27	16
	29	13

SS Carinae

Apr.	3	1
	6	9
	9	16
	12	23
	16	6
	19	13
	22	21
	26	4
	29	11

Z Draconis

Apr.	1	21
	3	5
	4	14
	5	23
	7	7
	8	16
	10	0
	11	9
	12	17
	14	2
	15	11
	16	19
	18	4
	19	12
	20	21
	22	6
	23	14
	24	23
	26	7
	27	16
	29	0
	30	9

δ Libræ

Apr.	1	0
	3	8
	5	16

δ Libræ

	d	h
Apr.	7	24
	10	8
	12	16
	14	23
	17	7
	19	15
	21	23
	24	7
	26	15
	28	23

U Coronae

Apr.	3	17
	7	4
	10	14
	14	1
	17	12
	20	23
	24	10
	27	21

R Arae

Apr.	1	2
	5	12
	9	23
	14	9
	18	19
	23	5
	27	15

U Ophiuchi

Apr.	1	20
	2	16
	3	12
	4	8
	5	4
	5	24
	6	20
	7	16
	8	13
	9	9
	10	5
	11	1
	11	21
	12	17
	13	13
	14	9
	15	6
	16	2
	16	22
	17	18
	18	14
	19	10
	20	6
	21	2

Minima of Variable Stars of the Algol Type.—Continued.

U Ophiuchi

	d	h
Apr.	21	23
	22	19
	23	15
	24	11
	25	7
	26	3
	27	19
	28	16
	29	12
	30	8

Z Herculis

	d	h
Apr.	4	1
	5	22
	8	1
	9	22
	12	1
	13	22
	16	0
	17	21
	20	0
	21	21
	24	0
	25	21
	27	24

RS Sagittarii

	d	h
Apr.	2	7
	4	16
	7	2
	9	12
	11	22
	14	8
	16	18
	19	4
	21	14
	24	0
	26	10
	28	20

V Serpentis

	d	h
Apr.	3	10
	6	21
	10	7
	13	18
	17	5
	20	16
	24	3
	27	14

RX Herculis

	d	h
Apr.	1	11
	2	9
	3	6
	4	3
	5	1
	5	22
	6	20
	7	17
	8	14
	9	12
	10	9
	11	6
	12	4
	13	1
	13	22
	14	20
	15	17
	16	14
	17	12
	18	9
	19	6
	20	4
	21	1
	21	22
	22	20
	23	17
	24	14
	25	12
	26	9
	27	6
	28	4
	29	1
	29	22
	30	20

SX Sagittarii

	d	h
Apr.	2	1
	4	3
	6	5
	8	7
	10	9
	12	11
	14	13
	16	14
	18	16
	20	18
	22	20
	24	22
	26	24
	29	1

RR Draconis

	d	h
Apr.	3	8
	6	4
	9	0
	11	20
	14	16
	17	12
	20	8
	23	4
	25	24
	28	20

RV Lyræ

	d	h
Apr.	4	1
	7	15
	11	6
	14	20
	18	10
	22	1
	25	15
	29	6

U Sagittæ

	d	h
Apr.	1	23
	5	8
	8	17
	12	3
	15	12
	18	21
	22	6
	25	15
	29	0

SY Cygni

	d	h
Apr.	5	21
	11	21
	17	21
	23	21
	29	21

WW Cygni

	d	h
Apr.	2	4
	5	11
	8	19
	12	3
	15	10
	18	8
	22	1
	25	9
	28	17

SW Cygni

	d	h
Apr.	1	24
	6	13
	11	3
	15	17
	20	7
	24	20
	29	10

VW Cygni

	d	h
Apr.	6	5
	14	15
	23	2

UW Cygni

	d	h
Apr.	1	23
	5	10
	8	20
	12	7
	15	18
	19	5
	22	16
	26	2
	29	13

W Delphini

	d	h
Apr.	3	5
	8	1
	12	20
	17	15
	22	11
	27	6

RR Delphini

	d	h
Apr.	2	9
	6	24
	11	14
	16	4
	20	19
	25	9
	29	24

RV Capricorni

	d	h
Apr.	1	12
	4	18
	8	0
	11	6
	14	12
	17	18
	21	1
	24	7
	27	13
	30	19

VV Cygni

	d	h
Apr.	1	13
	3	9
	4	21
	6	8
	7	19
	9	7
	10	18
	12	6
	13	17
	15	5
	16	16
	18	4
	19	15
	21	2
	22	14
	24	1
	25	13
	27	0
	28	12
	29	23

U Z Cygni

	d	h
Apr.	3	11

RZ Cassiop.

	d	h
Apr.	1	8
	2	12
	3	17
	4	22
	6	2
	7	7
	8	12
	9	16
	10	21
	11	2
	13	6
	14	11
	15	16
	16	21
	18	1
	19	6
	20	11
	21	15
	22	20
	24	1
	25	5
	26	10
	27	15
	28	19
	30	0

Approximate Magnitudes of Variable Stars on Feb. 1, 1907.

[Communicated by the Director of Harvard College Observatory, Cambridge, Mass.]

Name.	R. A. 1900. h	m	Decl. 1900. °	′	Magn.	Name.	R. A. 1900. h	m	Decl. 1900. °	′	Magn.
X Androm.	0	10.8	+46	27	14.0*d*	U Cassiop.	0	40.8	+47	43	13.0*d*
T Androm.		17.2	+26	26	12.0 *i*	V Androm.		44.6	+35	6	14.0*d*
T Cassiop.		17.8	+55	14	10.8 *i*	RR Androm.		45.9	+33	0	14.1*d*
R Androm.		18.8	+38	1	13.0 *i*	W Cassiop.		49.0	+58	1	13.0*d*
S Ceti		19.0	− 9	53	10.5 *i*	U Androm.	1	9.8	+46	11	11.8*d*
Y Cephei		31.3	+79	48	10.5*d*	S Piscium		12.0	+ 8	24	10 0*i*

Approximate Magnitudes of Variable Stars on Feb. 1, 1907—Cont.

Name.	R.A. 1900. h	m	Decl. 1900. °	′	Magn.	Name.	R.A. 1900. h	m	Decl. 1900. °	′	Magn.
S Cassiop.	1	12.3	+72	5	10.0*d*	T Can. Min.	7	28.4	+11	58	10.2 *i*
U Piscium		17.7	+12	21	13.0*d*	U Can. Min.		35.9	+ 8	37	9.5
R Piscium		25.5	+ 2	22	13.5 *i*	S Gemin.		37.0	+23	41	13.0*d*
RU Androm.		32.8	+38	10	13.0 *i*	T Gemin.		43.3	+23	59	9.0 *i*
Y Androm.		33.7	+38	50	13.8*d*	R Cancri	8	11.0	+12	2	10.6*d*
X Cassiop.		41.8	+58	46	9.5*d*	V Cancri.		16.0	+17	36	9.0 *i*
U Persei		52.9	+54	20	9.5 *i*	R T Hydrae		24.7	− 5	59	8.5
S Arietis		59.3	+12	3	13.8	U Cancri		30.0	+19	14	14.0*d*
R Arietis	2	10.4	+24	55	7.5	X Urs. Maj.		33 9	+50	29	11.0
W Androm.		11.2	+40	50	12.5*d*	S Hydrae		48.4	+ 3	27	12.0
Z Cephei		12.8	+81	13	11 0	T Hydrae		50.8	− 8	46	9.0
o Ceti		14.3	− 3	26	3.6*d*	T Cancri		51.0	+20	14	10.0
S Persei		15.7	+58	8	9.0	W Cancri	9	4.0	+25	39	10.8*d*
R Ceti		20.9	− 0	38	12.4*d*	Y Draco.		31.1	+78	18	13.5*d*
U Ceti		28.9	−13	35	10.5*d*	R Leo. Min.		39.6	+34	58	10.0*d*
RR Cephei		29.4	+80	42	13.5	R Leonis		42.2	+11	54	6.0 *i*
R Trianguli		31.0	+33	50	11.0*d*	V Leonis		54.5	+21	44	11.0*d*
T Arietis		42.8	+17	26	9.6	R Urs. Maj.	10	37.6	+69	18	8.0*d*
W Persei		43.2	+56	34	10.6*d*	S Leonis	11	5.8	+ 6	0	9.0
U Arietis	3	5.5	+14	25	8.5	R Comae		59.1	+11	20	13.0*d*
X Ceti		14.3	− 1	26	13.0*d*	T Urs. Maj.	12	31.8	+60	2	13.0*d*
Y Persei		20.9	+43	50	10.4*d*	RS Urs. Maj.		34.4	+54	3	13.5*d*
R Persei		23 7	+35	20	10.0 *i*	S Urs. Maj.		39.6	+61	38	10.0*d*
Nov. Per. No.2		24.4	+43	34	13.0*d*	R Can. Ven.	13	44.6	+40	2	8.0
T Tauri	4	16.2	+19	18	8.0 *i*	S Bootis	14	19.5	+54	16	11.4*d*
R Tauri		22.8	+ 9	56	12.8*d*	R Camelop.		25.1	+84	17	12.0*d*
W Tauri		22.2	+15	49	12.0	S Urs. Min.	15	33.4	+78	58	9.8*d*
S Tauri		23.7	+ 9	44	13.0 *i*	R Draconis	16	32.4	+66	58	10.0*d*
T Camelop.		30.4	+65	57	9.0 *i*	T Draconis	17	54.8	+58	14	12.0
X Camelop.		32.6	+14	56	13.4*d*	T Herculis	18	5.2	+32	0	8.0 *i*
V Tauri		46.2	+17	22	11.0 *i*	W Draconis		5.4	+65	56	12.0*d*
R Orionis		53.6	+ 7	59	11.0*d*	X Draconis		6.8	+66	8	11.0 *i*
R Leporis		55.0	−14	57	20	U Draconis	19	9.9	+67	7	12.5 *i*
T Leoporis	5	0.6	−22	2	10.0	R Cygni		34.1	+49	58	11.0 *i*
R Aurigae		9.2	+53	28	11.7*d*	χ Cygni		46.7	+32	40	6.0 *i*
S Aurigae		20.5	+34	4	10.6*d*	S Cygni	20	3.4	+57	42	11.0 *i*
W Aurigae		20.1	+36	49	<13	RS Cygni		9.8	+38	28	8.0
S Orionis		24.1	− 4	46	13.0*d*	U Cygni		16.5	+47	35	6.5
T Orionis		30.9	− 5	32	9.0 *i*	RZ Cygni		48.5	+46	39	9.6
S Camelop.		30.2	+68	45	10.5*d*	R Vulpeculae		59.9	+23	26	11.2*d*
RR Tauri		33.3	+26	19	10.0 *i*	X Cephei	21	3.6	+82	40	10.0 *i*
U Aurigae		35.6	+31	59	13.5*d*	T Cephei		8.2	+68	5	10.0*d*
Z Tauri		46.7	+15	46	11.0	S Cephei		36.5	+78	10	9.2*d*
U Orionis		49.9	+20	10	12.1*d*	RR Pegasi		40.0	+24	36	9.0 *i*
V Camelop.		49.4	+74	30	13.4	V Pegasi		56.0	+ 5	38	9.0 *i*
X Aurigae	6	4.4	+50	14	8.0	RT Pegasi		59.8	+34	38	9.6
V Aurigae		16.5	+47	45	10.5*d*	T Pegasi	22	4.0	+12	3	9.0 *i*
V Monoc.		17.7	− 2	9	9.5*d*	RS Pegasi		7.4	+14	4	9.0 *i*
S Lyncis		35.9	+58	0	10.3*d*	S Lacertae		24.6	+39	38	8.6 *i*
Nova Gem.		37.8	+30	2	<14	R Lacertae		38.8	+41	51	10.5*d*
W Monoc.		47.5	− 7	2	9.0 *i*	RW Pegasi		59.2	+14	45	12.0*d*
X Monoc.		52.4	− 8	56	8.0	R Pegasi	23	1.6	+10	0	11.1*d*
R Lyncis		53.0	+55	28	10.0*d*	V Cassiop		7.4	+59	8	7.5 *i*
RS Gemin.		55.2	+30	40	11.5*d*	W Pegasi		14.8	+25	44	7.5 *i*
R Gemin.	7	1.3	+22	52	12.0*d*	S Pegasi		15.5	+ 8	22	12.0*d*
R Can. Min.		3.2	+10	11	9.0 *i*	Z Cassiop.		39.7	+56	2	10.6 *i*
RR Monoc.		12.4	+ 1	17	13.0	RR Cassiop.		50.6	+53	10	12.5*d*
V Gemin.		17.6	+13	17	14.0	R Cassiop.		53.8	+50	50	13.0*d*
S Can. Min.		27.3	+ 8	32	9.6*d*						

The letter *i* denotes that the light is increasing, the letter *d* that the light is decreasing, the sign <, that the variable is fainter than the appended magnitude.

The magnitudes given have been compiled by Mr. Leon Campbell of the Harvard College Observatory, from observations made at the Vassar College, Whiteside, and Harvard Observatories, and by Felix deRoy and Paul Blanc.

Maxima of Variable Stars of Short Period not of the Algol Type.

Unless otherwise indicated the times of maxima only are given; and the times of minima may be found by subtracting the interval printed in parentheses under the names of the stars.

RW Cassiop.

	d	h
	(−5	19)
Apr.	3	8
	18	2

RX Aurigae

	(−4	0)
Apr.	1	17
	13	18
	25	18

Y Aurigæ

	(−0	18)
Apr.	4	10
	8	7
	12	4
	16	0
	19	21
	23	18
	27	14

T Monocerotis

	(−7	23)
Apr.	17	6

W Geminorum

	(−2	22)
Apr.	1	15
	9	13
	17	11
	25	9

ζ Geminorum

	(−5	0)
Apr.	1	1
	11	5
	21	8

V Carinæ

	(−2	4)
Apr.	5	8
	12	1
	18	18
	25	10

T Velorum

	(−1	10)
Apr.	1	3
	5	18
	10	10
	15	1
	19	16
	24	8
	28	23

W Carinæ

	(−1	0)
Apr.	4	10
	8	19
	13	4
	17	12
	21	21
	26	6
	30	15

S Muscæ

	(−3	11)
Apr.	9	5
	18	20
	28	12

T Crucis

	d	h
	(−2	2)
Apr.	1	8
	8	2
	14	19
	21	13
	28	7

R Crucis

	(−1	10)
Apr.	5	21
	11	17
	17	13
	23	8
	29	4

S Crucis

	(−1	12)
Apr.	1	8
	6	0
	10	17
	15	10
	22	2
	24	19
	29	11

W Virginis

	(−8	5)
Apr.	16	8
May.	3	14

V Centauri

	(−1	11)
Apr.	2	3
	7	14
	13	2
	18	14
	24	2
	29	14

R Triang. Austr.

	(−1	0)
Apr.	2	20
	6	5
	9	14
	13	0
	16	9
	19	18
	23	4
	26	13
	29	22

S Triang. Austr.

	(−2	2)
Apr.	6	19
	13	3
	19	10
	25	18

S Normæ

	(−4	10)
Apr.	6	9
	16	3
	25	21

RV Scorpii

	d	h
	(−1	10)
Apr.	1	4
	7	5
	13	7
	19	8
	25	9

RV Ophiuchi Minimum

Apr.	4	8
	8	1
	11	17
	15	10
	19	2
	22	19
	26	11
	30	4

X Sagittae

	(−2	22)
Apr.	4	9
	11	10
	18	10
	25	10

Y Ophiuchi

	(−6	5)
Apr.	16	15
May	3	18

W Sagittarii

	(−3	0)
Apr.	8	3
	15	17
	23	7
	30	21

Y Sagittarii

	(−2	2)
Apr.	2	23
	8	18
	14	12
	22	3
	29	17

U Sagittarii

	(−2	23)
Apr.	7	12
	14	6
	21	0
	27	18

β Lyrae

	(−3	7)
	(−3	2)
Apr.	7	18
	14	0
	20	16
	26	22

κ Pavonis

	(−4	7)
Apr.	9	2
	18	4
	27	6

U Aquilae

	d	h
	(−2	4)
Apr.	5	19
	12	19
	19	20
	26	20

XZ Cygni

	(−3	30)
Apr.	1	8
	2	6
	3	5
	4	3
	5	1
	6	0
	6	22
	7	21
	8	19
	9	17
	10	16
	11	14
	12	13
	13	11
	14	9
	15	8
	16	6
	17	4
	18	3
	19	1
	20	0
	20	22
	21	21
	22	19
	23	17
	24	16
	25	14
	26	12
	27	11
	28	9
	29	8
	30	6

U Vulpeculae

	(−2	3)
Apr.	5	14
	13	14
	21	13
	29	13

SU Cygni

	(−1	8)
Apr.	1	22
	5	18
	9	14
	13	11
	17	7
	21	3
	25	0
	28	20

η Aquilae

	d	h
	(−2	6)
Apr.	3	1
	10	6
	17	10
	24	14

S Sagittae

	(−3	10)
Apr.	2	10
	10	19
	19	5
	27	14

V Vulpeculae Minimum

Apr.	30	6

X Cygni

	(−6	19)
Apr.	13	2
	29	11

T Vulpeculae

	(−1	10)
Apr.	3	7
	12	4
	16	14
	21	1
	25	11
	29	22

TX Cygni

Apr.	10	3
	24	21

WZ Cygni Minimum Period 14^h.

Apr.	1	4
	2	8
	3	12
	4	16
	5	20
	7	0
	8	4
	9	8
	10	12
	11	16
	12	20
	14	1
	15	5
	16	9
	17	13
	18	17
	19	21
	21	1
	22	5
	23	9
	24	13
	25	17
	26	21
	28	1
	29	5
	30	9

Maxima of Variable Stars of the Short Period not of Algol Type.

Continued.

RV Capricorni			RV Capricorni			RV Capricorni			VZ Cygni			V Lacertæ		
	d	h		d	h		d	h		d	h		d	h
Period	10h	45m	Apr.	14	9	Apr.	27	19	Apr.	11	22	Apr.	7	10
Apr.	1	20		15	6		28	16		16	15		12	9
	2	17		16	4		29	14		21	15		17	9
	3	15		17	1		30	11		26	8		22	9
	4	12		17	23	VY Cygni			δ Cephei				27	8
	5	10		18	20	(−2		2)	(−1		10)			
	5	7		19	18	Apr.	1	7	Apr.	2	22		88.1906	
	7	5		20	15		9	3		8	7		Lacertæ	
	8	2		21	13		17	0		13	16		Minimum	
	9	0		22	10		24	21		19	0	Apr.	2	12
	9	21		23	8	VZ Cygni				24	9		7	22
	10	19		24	5	(−3		6)		29	18		13	9
	11	16		25	3	(−2		12)	V Lacertæ				18	19
	12	14		26	0	Apr.	2	4	(−1		17)		24	6
	13	11		26	22		6	22	Apr.	2	10		29	16

Elements of RX (33.1906) Aurigæ.—In *A. N.* 4150 Mr. A. Stanley Williams gives improved elements of this variable, determined from his own observations on 89 nights between January 22, and October 14 of last year.

Maximum = J. D. 2415083.43 Gr. M. T. + 11d.6263 E.

Variable Star 120.1906.—In *A. J.* 591 Mr. Naozo Ichinohe of the Yerkes Observatory gives the following approximate elements of the variable star 120.1906 Persei

Minimum = 1906 Nov. 29.0 (J. D. 2417544.0) + 6d.85 E

The star is B. D. +47°.692 and its position for 1900 is

R. A. — 2h 38m 58s.6 Decl. + 47° 43′.3

Its range appears to be from 8m.3 at maximum to 9m.5 or 10m.0 at minimum.

In *A. N.* 4150 Mr. A. A. Nijland also gives elements of this star with a period of 20d.596, and suggests that the period may possibly be one third of that number or 6d.865.

Minimum = J. D. 2417578.48 + 20d.596 E.

New Variable 155.1906 Cassiopeiæ.—In *A. N.* 4148 Messrs. Müller and Kempf give results of a series of photometric measures of the sixth magnitude star B. D. + 68°200 from which they find it to be variable with a period of 1.95 days. The position of the star for 1900 is

R. A. 2h 43m 02s.84 Decl. + 68° 28′ 27″.4 A. G. Christiana 500.

The range of variation is only 0.33 of a magnitude so that it will be a difficult variable for the amateur to handle. It appears to vary continuously, the light curve being symmetrical. The elements given are

Max. = 2417287.30 (1906 Mar. 17.30) + 1d.9498 E.

New Variable 156.1906 Persei.—In *A. N.* 4148 Professor E. Millosevich calls attention to a star which, on November 6, 1906, appeared to him to be of 8.5 magnitude and of a yellowish color, which is not given in the BD. It forms a small triangle with two other faint stars, the positions of the three for 1906.0 being

Star	R. A. h m s	Decl. ° ′	Mag.
A	1 23 55	+50 20.4	9.2
Variable	1 23 57	+50 22.2	
B	1 23 59	+50 21.3	9.7

The following observations of its brightness are given

1906	Mag.	Color			Mag.	Color
Nov. 6	8.5	yellow	Dec.	10	9.4	red
13	8.7	yellow		10	9 6	red
20	9.0	yellowish-red		14	9.7	red
22	9.1	yellowish-red				

The observations on December 10 were made by two observers, Bianchi and Millosevich.

Variable Stars 157 to 192.1906 Carinæ.—The list of thirty-six new variable stars, which was given on page 57 of the January number of *Popular Astronomy* have received from the *Astronomische Gesellschaft* committee the provisional numbers 157 to 192.1906.

Period and Light Curve of RS Aquarii.—In *A. N.* 4150 Professor E. E. Barnard gives a determination of the period and light curve of this variable.

The star appears to be constant at a maximum of 10.6 magnitude for about 50 days, descends to 14^m.1 at minimum in 85 days and recovers its normal in 78 days. The period given by Barnard is 212.917 days. Predicted minima are as follows: 1907 June 28, 1908, January 27 and August 27.

Eighteen New Variable Stars.—In the Harvard College Observatory Circular No. 124 Professor Pickering gives a list of sixteen new variable stars, discovered in the examination of late photographs of the Henry Draper Memorial, by Mrs. Fleming, and two found by examination of chart plates, one by Miss Annie J. Cannon and one by Miss L. D. Wells. The positions for 1900 and the approximate ranges of magnitude are given in the following table.

Harvard number	Constellation.	DM. No. °		R.A. 1900 h m	Decl. 1900 ° ′	Mag.
1305	Andromedae	+28	54	0 18.4	+28 51	8.7 - 9.9
1306	...		...	1 10.4	+41 12	8.0 -< 1.3
1307	Camelopardus	−57	806	4 22.4	+57 11	7.8 - 9.5
1308	Ursa Major	+52	1378	9 11.5	+51 10	11.1 - 11.9
1309	Carina	−64	1475	10 42.5	−65 05	8.4 - 9.6
1310	Draco	+66	780	12 52.5	+66 32	8.5 - 10.5
1311	Centaurus		...	13 13.2	−60 15	10.5 - 13.5
1312	Virgo		...	14 22.4	− 0 26	9.1 -<10.5
1313	Centaurus	−31	11294	14 28.1	−31 15	9.0 - 14.0
1314	Bootes	+31	2489	14 29.2	+32 11	8.9 - 10.0
1315	Lupus		...	14 52.3	−54 33	8.5 - 13.5
1316	Corona Bor.	+38	2698	15 43.0	+38 35	8.5 - 10.5
1317	Corona Bor.		...	15 52.2	+29 32	8.0 -<11.0
1318	Sagittarius		...	19 10.5	−39 47	9.8 - 12.4
1319	Aquila		...	19 52.0	− 9 37	9.6 - 11.5
1320	Delphinus	+15	4172	20 24.6	+15 56	8.9 - 9.8
1321	Delphinus		...	20 24.6	+15 56	11.8 - 12.8
1322	Lacertae		...	22 45.4	+40 30	8.2 - 9.7

Notes.—1305.—Period 0^d.49932. 1307.—Suspected of variability by Espin, A. N. 134, p. 123 and 145, p. 327. 1312.—Period 0^d.41224. 1314.—Period 0^d.49931. 1318.—Photographic observations of this star were exceedingly difficult, as it is involved in a nebula whose center is in the same right ascension, and is 14″ south of it. 1321.—A faint star about 20″ distant, following and south of 1320. 1322.—The preceding and southern of a pair of stars, about 40″ apart either of which might be identified as +40°5920, magn. 9.1.

GENERAL NOTES.

We were chagrined when we knew the result of a hurried attempt to secure a frontispiece for our last number, because of the failure of our engravers to reproduce the copy of Giacobini's comet. When Professor W. H. Pickering's article on the rotation of the tail of that comet came to hand, it seemed to us desirable to show a photograph of the comet at a time when the tail was widest and at a date mentioned in his paper. The copy sent was good, but the reproduction was shamefully bad. We had a very neat illustration of the Observatory at Edinburgh which was intended for that place; but the copy was lost on the way to the engravers.

A letter from the Rev. Joel H. Metcalf of Taunton, Mass., announces that he photographed the planet Oello (475) on 1907, Jan. $11^d\ 15^h\ 30^m.5$ G. M. T. in

A. A. $7^h\ 32^m\ 17^s.8$ (1855)
Dec. $+48°\ 22'\ 58''$ "

Note:—This object is of interest since its orbit has a greater eccentricity than that of any other known asteroid. A year or two ago it was in danger of being last. It is now very faint as its computed magnitude at opposition on January 12, 1907 was 14.1. See Harvard Circular 63, 101 and 103.

G. C. I.

Aitken's Tenth List of New Double Stars. R. G. Aitken, of Lick Observatory, has just published his tenth list of two hundred and fifty new double stars in the Bulletin of Lick Observatory, number 109. These double stars were discovered by the aid of the 12-inch and the 36-inch refractors. With this list, Mr. Aitken's published discoveries of new double stars now amounts to fifteen hundred.

New Secretary of the Smithsonian Institution. Melville W. Fuller, Chancellor of the Smithsonian Institution, Washington, D. C., announces that at the annual meeting of the Board of Regents held January 23, 1907, Charles Doolittle Walcott, L. L. D. was duly elected Secretary of that Institution to succeed the late Samuel Pierpont Langley.

Year Book No. 5 1906 of the Carnegie Institution is a volume that astronomers will look into with interest. The policy of that Institution has been to support, in general, two lines of scientific endeavor: one that should be thought of as the larger scientific enterprises, and the other to consist of the smaller lines of work. During the past about $460,000 was devoted to the first class of work, and about $100,000 to the second. The appropriations for the coming year amount to $661,300, divided in about the same proportion as last year, with $50,000 for administration and $70,000 for publication.

The one new feature in astronomy that is especially noteworthy is the attention given to Meridian Astronomy. Professor Boss of the Dudley Observatory, Albany, N. Y., is placed in charge of this new line of work.

This kind of work was established by the trustees of the Carnegie Institution at their meeting December 12, 1905, having for its object the positions and motions of the fixed stars. The plan includes, as an essential idea, the establishing of an observatory in the southern hemisphere. Just how this part of the plan is to be carried out is not yet known.

The Level of the Sun-spots. In a lecture recently given by E. W. Maunder, on sun-spot observations and some of their results, he refers to the level of the sun-spots in the following way for substance, as appears in the *Journal of the British Astronomical Association* Jannary 18, 1907.

The question is whether a sun-spot should be regarded as an elevation, a surface stain, or a depression. There is no doubt as to what a photograph of a spot suggests, viz: that we are looking into a hole. The way in which the penumbra appeared to bend over into the umbra seems to indicate that round the outside of the spot there is evidently an elevated region, which often seems to overhang the penumbra. Indeed in cases where the spot was bridged over, bright matter from this elevated region would actually be seen crossing the spot, so that the first impression from a direct scrutiny of a spot certainly was that it was a deep depression in the Sun. But there are some details which do not permit of the idea being held that they are dealing with a hole pure and simple. A good many years ago, when spots were first observed as notches in the limb, one or two astronomers rather rashly came to the conclusion that that was a proof that the spot was a depression, but of course a little reflection would show that a hollow would not show as a notch through being hollow, unless it was of enormous area, far more extensive than any spots are known to be. A dark surface stain would give the idea of a notch, so of course would a dark cloud above the surface. Photographs show a great variety in the apparent behavior of spots when seen strongly foreshortened near the limb; and often the nucleus appears as if less affected by the foreshortening than the spot of which it is a part, probably because the floor of the spot has a more or less convex form. The regions in which spots are formed are certainly more or less elevated; hence, though a spot is itself a depression, its floor might actually be as high as, if not higher than, the surface. Under any circumstances the depth of the spot must be extremely shallow as compared with its diameter. The breadth of a spot often amounts to 25,000 miles, and it is impossible to suppose that it could have a depth which would bear any relation to such an enormous distance. If in a spot one is looking through six or eight miles of extra depth, that fact could not fail to exert a great effect; yet when the great dimensions of the Sun are considered, a spot a few miles deep must be regarded as practically a mere surface stain.

Vol. II Annals of the Royal Observatory at Edinburgh, Scotland. Volume II of the Annals of the Royal Observatory at Edinburgh, Scotland, is at hand. It contains an introductory note by the present Director of the Observatory, Dr. F. W. Dyson, saying that the reduction of the observations was complete, and the printing of the catalogue, when he was appointed to succeed Dr. Copeland, the former Director, so that there was nothing to do but to carry the work forward.

The contents of this catalogue are a re-reduction of the star observations made by Thomas Henderson first Royal Astronomer of Scotland and his assistant, Alexander Wallace, in the years 1834 to 1845. This new and independent reduction of the meridian observations made at the old site of the Observatory on Calton Hill was brought to the epoch of 1840. If it has been thought wise to make re-reductions of catalogues as old as 1750 and 1850, on account of the better astronomical constants now available, and the more refined methods of reduction now in use, it seems that Dr. Copeland would be justified in bringing out earlier work, and putting it in shape to meet the needs of astronomers for better fundamental places for reference work.

We are glad to get this reference volume.

The New York Observatory and Nautical Museum. We learn from a recent number of *Science*, that a bill has been introduced into the legislature of the state incorporating the New York Observatory and Nautical Museum. We have before referred to the new enterprise in this publication. In the proposed charter it is stated that this new institution purposes to encourage and develop maritime interests in New York City, for the purpose of advancing general knowledge for the safe navigation of the sea, and of developing harbor facilities, prosecuting original researches in astronomy and navigation and kindred subjects, and affording instruction in the same. The incorporators are Frederick G. Bourne, Cornelius Vanderbilt, John E. Bourne, Edward S. Isham, J. D. Jerrold Kelly, Allison V. Armour, Edward H. Wales, George A. Cormack, John Neilson, Charles Lane Poor, William M. K. Olcott, Edward D. Adams, D. Delahnty and Addison Brown. Substantially the museum would be placed on the same basis as the museum of Natural History, and the Metropolitan Museum of Art. By the terms of the charter the city of New York is to provide the site and erect the building, and the corporation is to provide by subscription a sum not less than $300,000 for equipping the museum and the observatory and for carrying on the work to be undertaken by this new Institution.

Planet Tables. We have received a copy of a pamphlet of twenty-four pages, neatly printed and systematically arranged, by means of which its authors claim it is possible to locate the position of any member of the solar system within a few degrees, if not on the actual point of its true place in the heavens, at any hour of the day or night for the next twenty years. The pages of this descriptive pamphlet are closely printed in red and black ink, and serve as a key to a certain map or maps which it is supposed to accompany when in use. The authors of this work are Leon Barritt and Garrett P. Serviss. Our readers are familiar with the last named person as the author of some very useful books in elementary astronomy, especially, "Astronomy with the Opera Glass" and "Pleasures with the Telescope." Mr. Serviss' name connected with a work of this kind gives confidence to the claims made for it.

A Brilliant Meteor. About 10:12 Mountain Time on the evening of February 9, 1907 there flashed through the northern sky a particularly brilliant meteor. As seen at University Park it appeared at a point possibly one-third of the distance from γ Cephei to Polaris, thence took a downward course, passing to the right of β Cephei and disappearing a little above η Cephei and θ Cephei.

It was of dazzling brilliancy, considerably brighter than Jupiter and was of a decidedly bluish color. Some observers in the northern part of the state likened its appearance to that of an arc light; however it was easily as bright as a sky-rocket.

A little above η Cephei and θ Cephei, it broke into a number of fragments, three being clearly distinguishable and disappeared leaving the observer gazing into the inky darkness.

Denver, Colorado. D. S. Swan.

Computed Epochs of Maxima and Minima of Sun-spot Periods. From a brief paper prepared by S. Hirayama for the Tokyo Mathimaico-Physical Society some useful tables are taken that may do for reference. It would be interesting matter to publish Tables I and II, in addition to III and IV, that follow, for completeness, and to show more fully the study back to 1548. The fine large leaf diagram representing the facts of the paper graphically is also an important part of the paper.

The data of the last two will illustrate the character of the author's work.

TABLE III.

Computed Epochs of Maxima and Minima.

							From Min. to Max.	From Max. to Min.
Max.	1548.35	1615.13	1681.91	1748.69	1815.47	1882.25		
							3.85	7 50
Min.	1555.85	1622.63	1689.41	1756.19	1822.97	1889.75		
								6.59
Max.	1559.70	1626.48	1693.26	1760.04	1826.82	1893.60		
							4.25	
Min.	1566.29	1633.07	1699.85	1766.63	1833.41	1900.19		6.82
Max.	1570.54	1637.32	1704.10	1770.88	1837.66	1904.44		
							4.29	
Min.	1577.36	1644.14	1710.92	1770.70	1844.48	1911.26		7.47
Max.	1581.65	1648.43	1715.21	1781.99	1848.77	1915.55		
							3.77	
Min.	1589.12	1655.90	1722.68	1789.46	1856.24	1923.02		6.64
Max.	1592.89	1659.67	1726.45	1793.23	1860.01	1926.79		
							4.43	
Min.	1599.53	1666.31	1733.09	1799.87	1866.65	1933.43		6.82
Max.	1603.96	1670.74	1737.52	1840.30	1871.08	1937.86		
							4.35	
Min.	1610.78	1677.56	1744.34	1811.12	1877.90	1944.68		
Max.	1615.13	1681.91	1748.69	1815.47	1882.25	1949.03		
							4.16	6.97
							mean)	

TABLE IV.

Minima.				Maxima.			
Observed	Weight	Computed	Observed-Computed	Observed	Weight	Computed	Observed-Computed
1610.8	5	1610.8	0.0	1615.5	2	1615.1	+0.4
1619.0	1	1622.6	−3.6	1626.0	5	1626.5	−0.5
1634.0	2	1633.1	+0.9	1639.5	2	1638.3	+2.2
1645.0	5	1644.1	+0.9	1649.0	1	1648.4	+0.6
1655.0	1	1655.9	−0.9	1660.0	1	1659.7	+0.3
1666.0	2	1666.3	−0.3	1675.0	2	1670.7	+4.3
1679.5	2	1677.6		1685.0	2	1681.9	+3.1
1689.5	2	1689.4	+0.1	1693.0	1	1693.3	−0.3
1698.0	1	1699.9	−1.9	1705.0	4	1704.1	+1.4
1712.0	3	1710.9	+1.1	1718.2	6	1715.2	+3.0
1723.5	2	1722.7	+0.8	1727.5	4	1726.5	+1.0
1734 0	2	1733.1	+0.9	1738.7	2	1737.5	+1.2
1745.0	2	1744.3	+0.7	1750.3	7	1748.7	+1.6
1755.2	9	1956.2	−1.0	1761.5	7	1760.0	+1.5
1766.5	5	1766.6	−0.1	1769.7	8	1770.9	−1 2
1775.5	7	1777.7	−2.2	1778.4	5	1782.0	−3.6
1784.7	4	1789.5	−4.8	1788.1	4	1793.2	−5.1
1798.3	9	1799.9	−1.6	1805.2	5	1804.3	+0.9
1810.6	8	1811.1	−0.5	1816.4	8	1815.5	+0.9
1823.3	10	1823.0	+0.3	1829.9	10	1826.8	+3.1
1833.9	10	1833.4	+0.5	1837.2	10	1837.7	−0.5
1843.5	10	1844.5	−1.0	1848.1	10	1848.8	−0.7
1856.0	10	1856.2	−0.2	1860.1	10	1860.0	+0.1
1867.2	10	1866.7	+0.5	1870.6	10	1871.1	−0.
1878.9	10	1877.9	+1.0	1883.9	10	1882.3	
1889.6	10	1889.8	−0.2	1894.1	10	1893.6	

The theoretical Maxima and Minima are found from the graphical solution of the following equation:—

$$y = 47.8 + 43.8 \cos(6\ nt - 160°.2) + 11.8 \cos(12\ nt - 256\ .6) + 8.0 \cos(8\ nt - 169\ .9) + 7.1 \cos(4\ nt - 62\ .5)$$

Study of the Variable Stars. This publication makes much of variable star astronomy, because amateur observers can do useful work in this direction.

We have several times published brief descriptive articles for the sake of awakening interest among young observers in a line of work which they might do with useful results almost from the beginning of its study.

J. Miller Barr has recently prepared an article on "The Study of Variable Stars" which was printed in the Canadian Handbook for 1907. It is so well written and so useful to those who want to do such work that we will reprint part or all of it in the April number. Although it repeats matter that we have given before, we believe it will still be useful, because it deals well with fundamental things that variable star workers must know thoroughly and use constantly.

San Francisco Earthquake Record. Otto Klotz of Ottawa, Canada, sent us recently a photographic record of the condition of things at Ottawa, on April 17 and 18 which was a sheet of peculiar interest for some of the hours of those days, as the records plainly show that something in the scientific world was going on, that was *very unusual*! It was nothing less than the horrors of the San Francisco earthquake.

We have asked our friend, Professor Klotz, to describe that record quite fully, so that our readers may understand how he would know in Ottawa at once, of a terrible earthquake about 2000 miles away.

The Sun's Motion Relative to the Fainter Stars. In the *Astronomical Journal* No. 591, Professor G. C. Comstock, director of Washburn Observatory, Madison, Wisconsin, attacks the interesting problem: The determination of the Sun's motion relative to the fainter stars.

From previous study, Professor Comstock has determined that certain faint stars ranging from the ninth to the twelfth magnitudes are approximately of the same order of precision as the proper motions of the fifth and sixth magnitude stars of the Newcomb catalogue. He now has available the proper motions of 216 stars included, with very few exceptions, between the eighth and twelfth and thirteenth magnitudes. But certain of these stars are clearly binaries, in which the observed motion is orbital, and in some other cases the proper motion could not be determined certainly. After deducting all such stars, there remained 149 stars whose observed proper motions are supposed to be due to undisturbed translation through space.

A mathematical discussion of the motions of these stars is considered under the assumption of two clearly stated hypotheses which seem probable from reasons given later in the paper.

Professor Comstock reaches the following chief results in the form of an interesting summary:—

1. At least as far down the photometric scale as the twelfth magnitude the stars present measurable proper motions *e. g.*, two or three seconds per century.
2. The mean distance, and therefore the mean luminosity of these stars is considerably less than has been commonly assumed.
3. The proper motions, and presumably the parallaxes, of stars fainter than the ninth magnitude show a progressive increase with increasing distance from the galaxy.
4. We may provisionally employ the hypothesis that groups of stars widely distributed through space, but having a common center, possess no considerable flux relative one to the other.
5. Kapteyn's empirical formula representing stellar parallax as a function

of proper motion and magnitude may be extended to stars of the eleventh magnitude, and probably to fainter ones, without serious error in the mean result.

6. The motion of the Sun relative to the more distant stars (10^m and 11^m) is not widely different from its motion relative to the brighter lucid stars and the flux of the nearer parts of the stellar system with respect to those more remote is therefore small.

The interpretation to be placed upon the discordance between the position of the stellar apex here obtained and those otherwise derived, is reserved for another paper.

The Evening Sky for February. The most charming view that can meet the eye of the observer of the nightly sky comes in the early evening hours in the months of February and March on moonless nights. When the sky is perfectly clear, the zodiacal light in the south of west is a brilliant and a beautiful thing to look at with the naked eye. In latitude about 45° north it is often easily traced from the horizon nearly to the meridian as determined by our own vision which at present is not very sensitive. The triangular form of the zodiacal light as it appears to the eye, is peculiarly attractive when the Pleiades group is near the apex of the triangle. The added starlight is not strong enough to obscure the zodiacal light behind, but it does seem to add to it, and to give to it a definite contrast that is strongly helpful.

The whole southern field of the sky with Orion and the Galaxy as other leading features is most uniquely impressive to anyone who will stop long to look at it and to take into mind some of its richness and some of its inspiring awe.

One should also look towards the northwest horizon and upwards for twenty or thirty degrees to notice the difference between the Galaxy and the zodiacal light in that region of the sky. These two features probably will be seen in the best way by rapid direct and indirect glances. In other words pass the eye rapidly from one object to the other several times in succession; and in that way bring out the contrast which will appear strong on account of the dark space of the sky between them.

This is the time for those who want to improve their knowledge of the bright constellations to make a careful and a thorough study of them. Our constellation charts would be helpful to those who have little knowledge of star tracing, and wish to know more about it mainly by their own efforts.

A Rare Phenomenon of Jupiter's Satellites.—*A. N.* 4148 Mr. Enzo Mora, of Sequals, Udine, Italy, calls attention to the fact that on October 3, 1907, for a few minutes all four of the bright satellites of Jupiter will be invisible at the same time. According to the American Ephemeris, Satellite I will be in eclipse and occultation from $9^h\ 13^m$ to $9^h\ 38^m$ Greenwich mean time; Satellite II in transit from $7^h\ 46^m$ to $10^h\ 43^m$; Satellite III will be in eclipse from $4^h\ 30^m$ to $7^h\ 56^m$, and in occultation from $8^h\ 58^m$ to $12^h\ 37^m$; Satellite IV will be in occultation from $4^h\ 17^m$ to $8^h\ 52^m$. So during the ten minutes from $7^h\ 46^m$ to $7^h\ 56^m$ all four will be practically invisible. Again from $8^h\ 52^m$ to $8^h\ 58^m$ they will be invisible, III being partially hidden by the west limb of the planet before IV is free from the east limb.

Map of the Magnetic Declination for January 1905. The Department of Commerce and Labor, in the United States Coast and Geodetic survey, O. H. Titteman, Superintendent, has recently issued a large fine map of

the distribution of the magnetic declination in the United States for January 1, 1905, with isogonic chart and secular change tables. This useful work is by L. A. Bauer, inspector of magnetic work and chief of division of terrestrial magnetism. This chart and the descriptive matter with it is appendix four to the report for 1906.

Any astronomer who would like to compute orbits for one or more new asteroids would confer a favor by corresponding with Joel H. Metcalf of Taunton, Mass.

Errata. Page 82, line 19: for 'these' read 'those'. Page 87, lines 8 and 9. for 'momentum' read 'inertia'. Page 89, line 30: for 'θ'' read 'θ''. Page 90, line 23: for 'k' read k^2. Page 91, line 7: for 'ψ' read 'x'. F. J. B. C.

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The building and equipping of new observatories, the manufacture, sale or purchase of new astronomical instruments, with special reference to improvements and new designs, and the results of new methods of work in popular language, will be deemed very important matter and will receive prompt attention. It is greatly desired that all persons interested bear us in mind and promptly respond to these requests.

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